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PRELIMINARY DESIGN OF AN ACCIDENT INFORMATION RETRIEVAL SYSTEM (AIRS)

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report describes a reasonable design approach to a helicopter accident information retrieval system (AIRS) that records both crash impact and flight data which will aid accident investigations, reduce accidents, and provide a sound basis for formulating crashworthiness design criteria. The AIRS concept provided is characterized by low weight, low volume, and low cost, and is considered to be technically feasible. Though the AIRS concept defined represents a quantum step towards obtaining a compact low cost system, its ultimate application feasibility must be determined by trade-off analyses which show cost effectiveness. The results of this contract will be integrated into further research and development programs that will demonstrate the AIRS technical feasibility while assessing its application practicality.

LeRoy T. Burrows of the Military Operations Technology Division served as project engineer for this effort.

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This report covers the phase I activity entitled Concept Investigation and phase II entitled Preliminary Design and System Analysis. The report details the analyses involving requirements, parameters, trade-offs, and definition of a recommended AIRS.

The Phase I effort included the intense analysis of the airborne portion of the system since it is the most sensitive element in terms of size, weight, → over

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and cost. This included examination of the parameter and sensor requirements, survivability and software. Actual flight data was used to run a program on a large-scale computer to determine limits, accuracy, and sampling rate effects on flight data reconstruction and aircraft memory storage requirements.

Phase II included a detailed preliminary design of the AIRS. A preliminary hardware concept was established and the essential features of the recommended concept are included. The recommended system was analyzed to determine performance, weight, size, cost, installation, survivability, reliability, data retrieval, maintenance and functional test factors.

Results indicate that the current state of the art will allow an AIRS to be developed for installation on production UTTAS and AAH aircraft. The recommended system employs an all solid-state design including the mass data storage device. Factors of two or more improvements in size, weight, reliability, maintainability are indicated over current data recording systems.

SUMMARY

The conclusions, as given in this report, state that a solid-state data retrieval system can be designed for the Army and fully meet the requirements and design goals set forth. In addition, a single AIRS unit design can be implemented and installed on UH1, CH47, UTTAS, AAH and other Army aircraft with the necessary flexibility to accommodate each one. Also, data storage survivability equivalent or better than present day recorders used on commercial aircraft can be provided.

An examination of present state-of-the-art electromechanical crash recorders was made and it was concluded that even with a factor of two improvement in size and weight, the weight and size targets for an AIRS could not be economically approached. Further the maintainability requirements, limited life and reliability of current electromechanical devices, make the design goals of freedom from maintenance and extended life difficult to achieve. Driving any one of these above factors in the proper direction appears to drive the cost of these electromechanical devices even higher. For these reasons an electronic solid-state concept approach was chosen for further investigation.

Solid-state systems with and without self-contained microprocessors were examined with various types of data storage memory devices. It was found that, while an acceptable data only (no audio) recording duration can be achieved (greater than 30 minutes) without microprocessing for data compression, the lack of a processor in the unit would significantly degrade the self test capability of the system. A high level of self test is essential for minimal required periodic maintenance.

To estimate accurately what degree of data compression could be realized using a microprocessor to eliminate redundant data, a computer program was written to analyze candidate algorithms using actual flight data taken from a CH-53 helicopter. The computer study showed that a combination of fixed-frame, fixed-time interval and variable-frame techniques utilizing floating limits resulted in almost an 18:1 data compression factor.

A candidate parameter list was developed with the Army. Each parameter was applied to the concept to determine the incremental cost, size, weight, reliability, etc, of adding parameters starting with those judged to have a higher priority. Certain parameters such as EGT, vibration, and separate lateral and longitudinal flight g inputs and sensors were eliminated based on their incremental cost relative to their worth. However, the Army requested that a separate vertical flight g channel and sensor be included.

Audio voice parameters were also critically examined to ascertain the implications of providing one voice channel with a minimum average recording time of approximately five minutes in a solid-state system. The analysis showed that using bubble memory technology with a memory capacity of 400,000 bits, and using state-of-the art techniques for minimizing the bit rate for intelligible speech, a single-channel capability could be provided at an incremental cost of 80% of the recommended data

only recording approach. Weight and size increases were correspondingly high.

Voice audio was therefore not included in the recommended system parameter list.

Survivability of the data storage device was also examined. The survivability criteria and success rates were studied for current crash recorders used in commercial aircraft. As a baseline these same survivability requirements were imposed on the solid-state data storage module. The delta cost and weight associated with this degree of protection versus no protection beyond adherence to military specifications was quantified. The recommended system includes the protective enclosure on the basis that the cost and weight delta is not significant compared to the increased number of accidents where data will be obtained. Also, operational survivability through the crash impact profile was addressed with respect to the AIRS unit. The unit was designed to operate when subjected to forces up to 150 g's by sacrificing unit repairability at a minor weight penalty with no significant increase in cost.

The candidate parameter list established with the Army is as shown in Table 1. The final Army approved parameters for the AIRS are indicated along with those parameters identified for a minimum impact measuring only AIRS. An intermediate AIRS was also defined with its list of parameters also included in Table 1.

The recommended AIRS has a microprocessor and 32,000 bits of EAROM. Intermediate AIRS capability was defined as having a microprocessor, 32,000 bits of EAROM, and the mini AIRS parameters plus pitch, roll and engine torque. The mini AIRS had no microprocessor and included 8,000 bits of EAROM storage.

The relative cost, weight, size, and average recording time against the above three successively more comprehensive systems was developed. These systems were compared to an assumed state-of-the-art electromechanical recorder.

At the Program outset, a weight goal of 7 pounds and a volume goal of 200 cubic inches was established. Also, a 30-minute average recording time evolved as a goal after the computer study was completed that estimated an achievable data compression ratio. These goals were determined to be realistic. The weight and volume goals do not include installation effects which will vary somewhat with the particular airframe, since in some cases transducers must be added where no electrical signal exists. Also, wiring run weights and installed cost will be different.

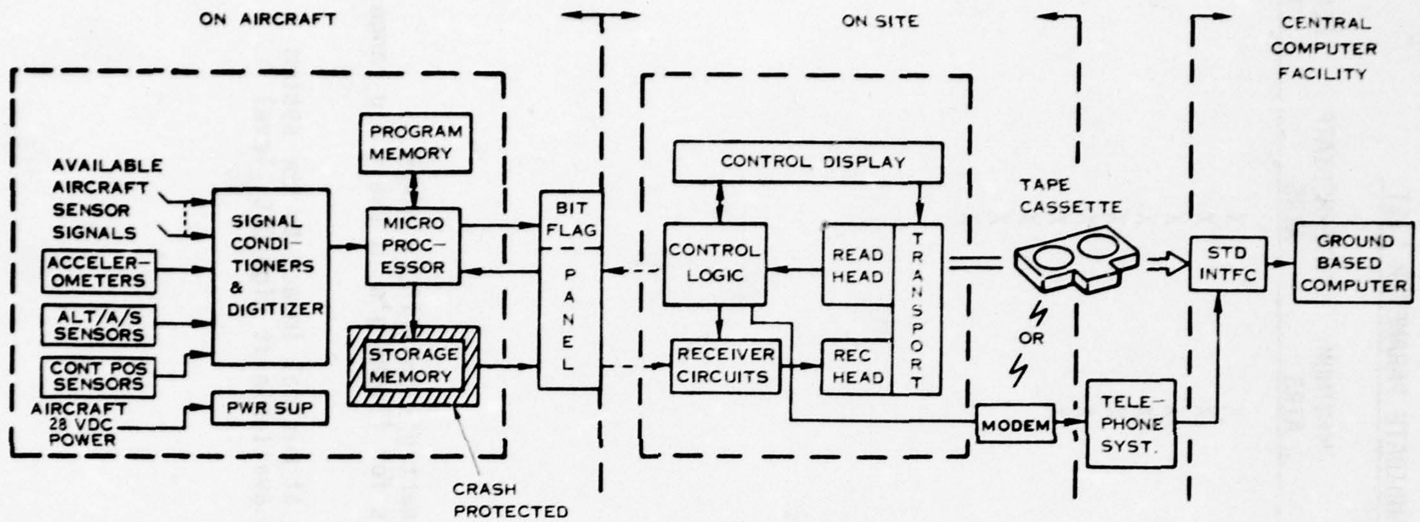
The concept of the AIRS operations is shown in Figure 1. The AIRS Unit (one per aircraft) takes the sensor electrical signals and converts them to digital words. The microprocessor operates on the words in accordance with a set of "rules" stored in the program memory. If a data point changes in accordance with the set rules, the processor inserts the word into a "cigarette pack" sized survivable solid-state data storage module. The module protects and stores indefinitely (without any electrical power applied) the data leading up to the incident. Data on impact g's magnitude and duration is also stored.

TABLE 1. AIRS CANDIDATE PARAMETER LIST

	CANDIDATE PARAMETER LIST	MINIMUM AIRS	INTERMEDIATE AIRS	RECOMMENDED AIRS
	1. Relative Time	X	X	X
	2. Airspeed	X	X	X
	3. Heading	X	X	X
	4. Altitude	X	X	X
*	5. Vertical Accel.	X	X	X
*	6. Long. Accel.	X	X	X
*	7. Lateral Accel.	X	X	X
	8. Pitch Attitude		X	X
	9. Roll Attitude		X	X
	10. Engine Torque		X	X
	11. Rotor RPM			X
	12. Engine RPM			X
	13. Cockpit and Comm. Audio			
	14. Fire Detection Discretes			X
	15. Chip Detection Discretes			X
	16. Hydraulic System Discretes			X
**	17. EGT			
	18. Long. Cyclic Position			X
	19. Lateral Cyclic Position			X
	20. Collective Position			X
	21. Pedal Position			X
	22. Vibration			
	23. Radar Altitude			X

* - Three axes of impact g's in ± 150 g range.
One vertical axis for flight g's in the ± 5 g range.

** - EGT can be added at minimal impact to the system if the signal is available at high D.C. level on aircraft.



SIGNALS/SENSORS

- ACCELERATIONS
- AIRCRAFT ROTATIONAL POSITIONS
- ENG POWER AND ROTOR SPEEDS
- CONTROL INPUT POSITIONS
- FAULT WARNING DATA
- ALTITUDE

FLIGHT UNIT

- DATA ACQUISITION
- SYNC/TIME INSERTION
- FLT DATA STORAGE PER PROGRAMMED INSTRUCTIONS
- SELF TEST

PORTABLE GROUND UNIT

- FLT/IMPACT DATA TRANSFER AND STORAGE
- REPLAY INTO PHONE SYSTEM
- SELF TEST

EXISTING FACILITIES

- TIME RECONSTRUCTION
- DATA ANALYSIS
- REPORT GENERATION
- FILE KEEPING

FIGURE 1. ACCIDENT INFORMATION RETRIEVAL SYSTEM (AIRS)

A portable ground unit (PGU) is used to extract the data from the protected memory module. Several manufacturers currently build devices which meet PGU operational requirements. The PGU records the data on a Phillips type cassette. The cassette is then either sent to a central computing facility or read into the telephone system via standard available hardware. Existing Military computing facilities can be used to process and reconstruct the data for timely use in the investigation process. Only one PGU per 50 or more aircraft need be obtained since its use will be occasioned only by accidents or incidents.

The basic design characteristics of an AIRS are given in Table 2.

TABLE 2. AIRS - DESIGN CHARACTERISTICS

Completely Solid-State - Electronics and Data Storage.

Microprocessor in the airborne unit to sort out data that is not changing appreciably and to allow Built-in-test to a high level.

Solid-State Electrically Alterable Memory System for data. Will hold data indefinitely without power.

Data Module Survivability per TSO C51a (Specification for commercial jet transport recorder survivability) Modified for greater thermal survivability and underwater exposure.

150 g 10 Millisecond Impact Survivability of the electronics unit.

Input Parameter Capability	18 Analog 18 Discretes
Average Flight Time Data Storage	30 Minutes
Unit Weight	7.62 Pounds
Unit Size	190.5 cu. in. (5.0 X 6.35 X 6.0 in.)
Electrical Power	25 Watts
Unit Mature Reliability Estimate (MTBF)	10,204 Hours
Sensors	Three axes of impact acceleration and one axis of flight g's. Pressure transducer for altitude measurement.
Sensor Weight	1.95 Pounds (UH60A Application)
System Mature Reliability Estimate (MTBF)	7,692 Hours
System Maintainability - (Organizational plus Intermediate Scheduled and Unscheduled)	1.14 Maintenance Man Hours/1000 Flt. Hours
Typical Installed - Weight of Wiring, Mounts, Brackets, etc. in new Aircraft application	5.76 Pounds
Typical Man Hours to install in new Aircraft in lot quantity 130 Aircraft	100 Man Hours

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1.0 INTRODUCTION

The objective of the AIRS Analysis and Design, as reported herein, is to first determine an AIRS configuration on the basis of chosen trade-off factors. These include functional capability, cost, weight, crash survivability and other factors such as life, reliability and maintainability, which impact the best compromise approach to providing a data retrieval capability on Army helicopters for investigation of mishaps. From the determined AIRS concept, a detail preliminary design is accomplished.

New and existing helicopters are addressed, and a candidate parameter list is prepared consistent with the Army's required features and design goals. The state-of-the-art is reviewed and extrapolated to estimate how close contemporary systems could come to meeting the goals and objectives. More advanced concepts using solid-state techniques are studied and various systems formulated.

Several design concepts are explored in terms of storage memory types and sizes for the chosen overall system concept. For these design concepts, size, weight, cost and the other factors were quantified against the functional areas of recording duration and number and type of input parameters. From this tabulation, a recommended system concept is identified.

Other major areas analyzed and reported herein are:

* Crash and fire survivability and the impact on the system weight, memory size and volume versus elimination of specific survivability mechanical enclosures beyond standard military specification.

* Design to operate through chosen impact levels for up to five seconds in an operational state.

* A system which only records three basic flight parameters and three axis impact accelerations is also concepted and compared to the more comprehensive recommended AIRS concept.

The recommended system as accepted by the Army for preliminary design was further defined to obtain refined factors of size, weight, reliability, maintainability, survivability and cost for a new aircraft installation. The installation and aircraft interface is also addressed on the UTTAS helicopter as being typical of a new aircraft installation.

2.0 AIRCRAFT ACCIDENT DATA RETRIEVAL SYSTEMS

2.1 NEED FOR RECORDED DATA

Aircraft accidents continue to occur, often with tragic and expensive consequences. When an accident does happen, it is extremely valuable to determine the cause. This information is needed to reduce the probability of future accidents and the consequences in terms of cost, loss of life or injury by improvements in equipment, procedures, or training. Thus considerable effort is expended in the investigation of accidents.

Army Aviation, as is the case with commercial aviation and other branches of the US Military, has definite objectives and procedures to cope with accidents as they occur. AR 95-5 entitled Aircraft Accident Prevention, Investigation and Reporting provides the requirements for the investigation analysis and reporting process.[1]

As stated in Chapter 2.0, Paragraph 2.3 of AR 95-5, "Data gained from accident experience are an important part of the prevention effort. To be most valuable, these data must be timely, properly assembled, analyzed, evaluated, and made available in useful, manageable information to the commander and other appropriate agencies. In Paragraph 2.6(1) under "Investigation and Analysis" the following is stated: "Accurate and timely mishap investigations and analysis are essential to aviation safety."

The need for recorded data is indicated from the above Army statement which stresses timeliness and accuracy and the fact that presently available mishap information is often sketchy, qualitative, and opinionated.

Information about an accident presently comes from a variety of sources, including reports from the crew and passengers, eyewitness accounts, examination of the wreckage, impacted area, and collateral data such as weather conditions, operational records, and maintenance records.

In many accidents, however, there has not been enough information to clearly identify the cause. In serious accidents that were fatal to the crew, the desire to determine the cause is even greater but one important source of information is not available.

In many cases there are no eyewitness accounts, or the ones available are not in agreement. Also, in most cases it is impossible to determine from the wreckage what the events were before impact. In some cases the evidence is destroyed by fire.

These situations have led to cases where the probable cause was undetermined, inaccurate, or too general to provide any real assistance in preventing future accidents. Many accidents have been charged to "pilot error" without determining the factors which created the potential for the pilot error.

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[1]U.S. Army Regulation, No. 95-5, AIRCRAFT ACCIDENT PREVENTION, INVESTIGATION, AND REPORTING. Effective date 1 April 1975.

For these reasons, there has been a strong demand from accident investigators for hard quantitative data leading up to and during the accident. This data would be a recording of as many critical parameters as possible, which would be preserved for later analysis. This demand has become stronger as increased aircraft complexity and performance have made the investigation process more difficult, and as the size and expense of aircraft have made the consequences of an accident more severe. However, in commercial and other military services the demands have only been met when the aircraft is large and expensive and/or when commercial regulations are invoked. This is in spite of the fact that contemporary systems are large, relatively unreliable, and expensive.

The value of recorded data is illustrated by the recent awareness of the danger of wind shear, particularly during landing.[2] An Iberian Airlines DC-10 hit short of the runway during an Instrument Landing System (ILS) approach at Boston's Logan International Airport in December 1976. This aircraft was equipped with a new digital flight data recording system that included even more than the required FAA parameters. Using this data, investigators were able to show for the first time that wind shear was a primary cause of the accident. Without the recorded data the primary cause would probably have been "pilot error". The more complete analysis of this accident and a much more serious one later (an Eastern 727 at JFK in June 1975) allowed the conditions to be reproduced in a simulator. It was found that immediate recognition of the situations and immediate action would have been required by an experienced pilot to prevent the accidents. In the second accident,8 out of 10 pilots believed they might have crashed in a similar situation. This analysis has lead to considerable effort in improved training, improved procedures, and the development of ground and airborne detection equipment for wind shear conditions, which promise to save many lives and aircraft in the future.

The utility and specific need for recorded data is outlined as follows.

Improved Reaction Time in Identifying and Correcting Aircraft Hardware Deficiencies

By having data available from an on-board device the investigative and analysis time can be shortened. In some cases more than one similar accident may occur before the basic cause is determined and the deficiency corrected. Substantive recorded data from such accidents can reduce the incidnece of similar accidents. Timely identification of causes can mean reduction in the time the fleet is grounded while the investigative and corrective process takes place.

[2] Roberts, Carol A., FLIGHT RECORDERS AND AIRCRAFT SAFETY, National Conference, Association for Computing Machinery October 1976.

Improved Reaction Time in Identifying and Correcting Operational Definciencies

In general, the same comments under hardware deficiencies above apply. Early identification of unsafe procedures and maneuvers as determined by recorded data can result in issuance of advisories and directives to reduce the reoccurrence of similar incidents.

Improved Aircraft Crashworthiness and Survivability

Availability of recorded data such as impact accelerations measured in the crew space can be used to assess and improve the future crashworthiness of aircraft seats, crew restraints, structure, fuel systems and life support systems.

Improved Accident Information Data and Analysis Accuracy

In present Army aircraft operations some data is accumulated through analysis of the wreckage, site scars and any eyewitness accounts. These data are generally of very limited accuracy if available at all. Vastly improved accuracy and data availability will allow the investigation process to be brought to a more accurate conclusion.

Reduced Accident Investigation Costs

Having available data relating to the flight profile and events prior to and including an incident will reduce the investigative and analysis effort. Calendar time to bring the process to a conclusion will be shortened and the man hours to accomplish the task reduced. The cost of the investigation and analysis effort will thereby be reduced.

2.2 HISTORICAL BACKGROUND

The requirement for recording data on commercial airline aircraft was first proposed in 1941 and again in 1947 but was abandoned in each case because the technology was not available to reliably perform the function at a reasonable cost. In 1957, the requirement was finally made firm for commercial aircraft of over 12,500 pounds that flew over 25,000 feet. The requirement was made to assure coverage of the new jet transports that were being added to the commercial fleet. The required parameters were limited: time, altitude, airspeed, heading, and vertical acceleration. The technology that was then available to meet these requirements used scribe marks on metal foil as the recording medium. Generally these systems used the aircraft's compass system for heading, contained pressure sensors for altitude and airspeed, and a dedicated sensor for vertical acceleration. These systems are still used in the majority of commercial airlines and are still being delivered on some new aircraft. While limited, these systems have nevertheless been important in obtaining data in more than 500 accidents investigated by the National Transportation Safety Board or its predecessor.

In the same time period a requirement for voice recording was added. These recorders used magnetic tape in a reversing reel configuration that stored the previous 30 minutes of audio data. The tape was encased in a separate enclosure that protected it from the crash environment. Up to four channels are recorded, including a cockpit area microphone. These recordings have also proven to be very valuable in determining mishap causes. They are valuable for detecting information from noise other than voice, such as engine noises, flight surface, landing gear, extensive vibration noise, and control lever clicks.

The basic flight data recorder with only four parameters plus time, while invaluable, does not give nearly as much information as desired by aircraft accident investigators. In 1972, requirements were expanded for all aircraft receiving their certification after 1969. The effective date of this new requirement was chosen to assure that all new wide body aircraft were covered. The expanded parameter list along with range, accuracy and recording rate is given in Table 3. New electronic digital technology was available which allowed these requirements to be met at a reasonable economic level. Most systems that have been produced to this requirement consist of two major units. One is an electronic digital data acquisition unit that multiplexes a large number of signals, converts analog signals to digital form, and combines all data into a single digital stream. This unit can be placed near the sensors to minimize wire runs. The serial digital signal is sent to a separate crash-protected digital magnetic tape recorder. The recorder can be placed in a location that minimizes the risk of being damaged. The recorder stores the last 25 hours of data. A sonar pinger activated by water immersion is usually included.

TABLE 3. CURRENT FAA COMMERCIAL AIRCRAFT FLIGHT RECORDER SPECIFICATIONS

INFORMATION	RANGE	ACCURACY, MINIMUM (RECORDER AND READOUT)	RECORDING INTERVAL MAXIMUM (SECONDS)
Time		± 0.125% per hour, except accuracy need not exceed ± 4 seconds.	60.
Altitude	-1,000 ft to max certificated altitude of aircraft.	± 100 to ± 700 ft (see Table I TSO-C51a; FAR § 37.150).	1.
Airpseed	100 to 450 KIAS or 100 KIAS to 1.0V whichever is greater	± 10 knots at room temp. ± 12 knots at low temp. (see Table III, TSO-C51a: FAR § 37.150).	1.
Vertical Acceleration	-3g to + 6g	± 0.2g stabilized ±10% transient (see TSO-C51a).	0.25 (or 1 sec. in which ± peaks are recorded).
Heading	300°	± 2°	1.
Pitch Attitude	± 75°F	± 2°	1.
Roll Attitude	± 180°	± 2°	1.
Lateral Acceleration (in lieu of sideslip angle)	± 1.0 g	± .05g stabilized ± 10% transient.	0.25 (or 1 sec. in which ± peaks are recorded).
Sideslip Angle (in lieu of Lateral Acceleration).	± 30°	± 2°	0.5
Pitch Trim Position	Full range	± 1° or ±5% whichever is greater.	2.
Control Column or Pitch Control Surface Position	Full range	± 2°	1.
Control Wheel or Lateral Control Surface Position	Full range	± 2°	1.
Rudder Pedal or Yaw Control Surface Position	Full range	± 2°	0.5
Thrust of Each Engine	Full range forward	± 2%	4.
Position of Each Thrust Reverser.	Stowed and full reverse		4.
Trailing Edge Flap or Cockpit Flap Control Position	Full range (or each discrete position)	± 3°	2.
Leading Edge Flap or Cockpit Flap Control Position	Each discrete position		2.
Angle of Attack (If recorded directly).	-20° to +40°	± 1	0.5

The requirement for recording systems has been studied and various directives and advisories have been issued by the US Air Force and Navy. Some systems have been installed on large Air Force aircraft such as the C-5A, C-141, and C-135 transports. A system has been specified and developed for the Air Force B-1 prototypes. Some of these systems increase the probability of data retrieval by ejecting a data pack from the aircraft when high acceleration or breakup is detected. A radio beacon is included to aid in locating the package containing voice and audio data. Air Force aircraft currently in the evaluation or procurement cycle such as Command Post, the advanced transport/cargo aircraft (versions of current commercial wide-body aircraft), and the medium STOL transport will have crash recording systems installed that are versions of equipment currently being applied for commercial wide-body aircraft as described above. A policy statement exists within the Air Force which advises the use of crash recorders and position indicators where possible.[3] For large aircraft such as those mentioned above, the policy statement can be met with contemporary hardware. For smaller aircraft, such as trainers and fighters, the requirements of the policy statement cannot currently be fulfilled because of the high cost, size, and weight of available equipment. As a result, no small aircraft, either in inventory or new, have such a system installed for routine military operations.

Within the US Navy, a directive is currently in force that requires an ejectable type system on all new aircraft being delivered to the fleet.[4]

The system contains voice and data and includes a radio beacon located within the ejectable portion of the system. Larger Navy aircraft currently being delivered, such as the P3 and S3, have such systems. However, for smaller aircraft, such as the F14 and F18, the requirement has been waived because of the size, weight, and cost associated with present systems.

2.3 POTENTIAL FOR NEW TECHNOLOGY TO MEET NEW FLIGHT DATA REQUIREMENTS

The history of flight data recording for accident investigation has shown some correspondence between an ever-increasing need for data and the development of practical but limited basic data recording. The advent of the wide-body jet, with even greater size, cost, and the tremendous consequences of a major accident demand even more data which was made practical by the development of first-generation digital electronic technology and state-of-the-art magnetic tape recorders. The two recent developments in electronic technology that are most significant for flight data recording are microprocessors and solid-state memories. Microprocessors are becoming so economical that the cost of the processing element itself is a small portion of the cost of the overall system.

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3 U.S. Air Force, AIR FORCE POLICY ON FLIGHT DATA RECORDERS AND CRASH POSITION INDICATORS, Chief of Staff Policy Letters dated 16 June 1973, signed by General John D. Ryan.

4 U.S. Navy, CRASH POSITION INDICATOR/FLIGHT DATA RECORDER SYSTEMS FOR NAVAL AIRCRAFT. Chief of Naval Operations message CNO 1416102 April 72.

The processor can be used to increase the effectiveness of the recording process by providing efficient automatic control of the data collection process and by allowing preprocessing of the data, which can greatly reduce the amount of memory required. New memory technology, such as bubble domain memory and metal-nitrite-oxide semiconductor (MNOS), allows a totally solid-state design which greatly reduces the cost of ownership by low material costs, increased reliability, and no periodic maintenance.

These developments make the application of data retrieval systems feasible on aircraft that were previously thought to be too small.

This new technology may have its greatest importance in Army aviation, where previously cost and maintenance problems did not allow the use of flight or crash data recording systems.

3.0 SYSTEM REQUIREMENTS

The basic requirements for the system are:

Required Army Features

(1) Record crash data, including initial crash impact forces.

(2) Record flight data.

(3) Design life of 5,000 hours.

(4) Crash- and fire-survivable data storage unit (protection and location).

(5) Automatic operation with aircraft power actuation.

(6) In-flight aircraft emergency shutdown procedures shall not interrupt power to the AIRS.

(7) Data retrieval without removal of any AIRS components from the aircraft.

Army Design Goals (Requirements that must be applied to some degree and/or traded off)

(1) System integration for minimum cost, weight, and size.

(2) Primary emphasis directed toward application to new helicopter systems but shall also be compatible with current systems.

(3) Maximum use of existing aircraft circuits and sensors.

(4) Simple functional check capability.

(5) Minimum addition of sensors and associated wiring to aircraft.

(6) Ease of installation and removal from aircraft.

(7) High degree of reliability.

(8) Minimum ground-based hardware and software for data retrieval.

(9) Data output compatible with existing computer systems (i.e., development of new computer systems is beyond the scope of this effort.

(10) Ability to operate for up to 5 seconds after initial crash impact.

(11) Data unit survivable in submerged aircraft for up to four weeks.

(12) Maintenance free.

The standard military equipment specification requirements in MIL-E-5400, Class IA, are also design goals.

3.1 CANDIDATE PARAMETER LIST

The basic function of an accident information retrieval system is to sense and store a set of data parameters which will supplement the investigation in determining the cause of the mishap. Data is also desired which will help determine the survivability of the impact as it relates to structures and ultimately the crew and passengers. It is not practical or possible to gather all information that might be needed to assure that the cause can be determined. Some parameters that might be desirable would be too expensive to obtain. Also, if too many parameters are collected, either the required signal conditioning and recording capacity will be too large and expensive or the recording interval will be too short. One of the primary objectives of the analysis was to determine the parameter list that gives a reasonable amount of data that can be obtained at a realistic total cost and weight.

Some of the characteristics of the parameter list which need to be considered in determining the most effective design of the total system are:

1) the order of priority of the parameter (as it relates to its technical worth)

2) The incremental cost of each parameter to the system.

3) The incremental weight of adding the parameter to the system.

4) The desired accuracy.

5) The desired sampling interval (this can be an input sample interval prior to possible preprocessing or a maximum sample interval with no preprocessing)

6) The change in a parameter that is significant enough to be noted.

Notes 2) and 3) above are airframe-dependent (i.e., is the signal available or must a sensor be added). Note 6) above relates to those candidate systems using preprocessing to minimize data bulk.

If the parameter is low on the priority list and its incremental cost outweighs its technical worth, the parameter is dropped. In some cases if the incremental worth of a lower priority item is judged to be much greater than its incremental cost, it may be added to the list. From this process, a cost-effective system capability is estimated.

The desired accuracy, sample rate, and threshold of significant change is used to determine the requirements for the electronic interface, the data processing requirements, and the memory size. For example, for a digital system the required accuracy determines the size of the analog to digital converter and the number of bits in a data word. The recording threshold value is used to determine the amount of data compression* that is possible. The word size, sample rate, and degree of compression will determine the amount of time that can be recorded in a given memory.

The desired candidate parameter list was assembled using parameters found to be prevalent in industry. These parameters have been reviewed with regard to inclusion and priority with personnel from the U.S. Army Agency for Aviation Safety and other agencies at Ft. Rucker who determine accident investigation procedures, maintain accident information computer facilities, and train accident investigators. This list is given in Table 4. The first seven parameters were specified by the Army for a data at impact measuring system only (Mini-AIRS). The preliminary maximum sampling interval and accuracy are given. The preliminary value of the change required to cause a recording is also given. This value is very important in determining the memory requirements for candidate systems using preprocessing. The final value of delta threshold should be defined using actual flight data.

Accelerations are listed twice. A higher priority is placed on impact accelerations. Detection of the peak and duration of an acceleration pulse is desired. Sample rates as high as 600 per second must be considered to insure that the peak is not missed. Flight accelerations have a lower priority, and the dynamic range and the sampling rates can be much lower. The trade-offs involved in using one or two sets of sensors for these two requirements were considered in this study also.

A trade-off of one versus two separate sensors for measuring impact and flight g's centers around the maximum desired impact g range and the resultant accuracy in the lower flight g range versus cost to obtain the accuracy using a single high accuracy sensor or separate sensors. Also a factor is whether a colocation of impact and flight g measurement is acceptable. The maximum impact g range desired is a function of what is to be measured and whether extrapolation of maximum impact g's to another location is feasible and/or desirable.

* For those candidate systems where preprocessing may be used.

TABLE 4. CANDIDATE PARAMETER LIST

PARAMETER & RANK	MIN. AIRS PARAMETERS	MAXIMUM SAMPLING INTERVAL	CHANGE REQUIRED FOR RECORDING * (THRESHOLD)	ACCURACY OF POINT RECORDED EXCLUDING SENSORS
1. Time (elapsed)	X	0.25 sec	NA	NA
2. Airspeed	X	1 sec	15 Kn.	5 Kn.
3. Heading	X	2 sec	10°	5°
4. Altitude	X	1 sec	50 ft.	20 ft.
5. Vert. Acceleration	X	low enough to detect peak and duration of impact.	3-5 g's	~1 g
6. Longitudinal Accel.	X		3-5 g's	~1 g
7. Lateral Accel.	X	Output once each 1/4 sec. if over threshold	3-5 g's	~1 g
8. Pitch Attitude		2 sec	10°	1°
9. Roll Attitude		2 sec	10°	1°
10. Engine Torque		1 sec	5%	2%
11. Rotor RPM		1 sec	5%	2%
12. Engine RPM		1 sec	5%	2%
13. Cockpit and comm. Audio		TBD	TBD	TBD
14. Fire Detector Discrete		1 sec	NA	NA
15. Chip Detector Discretes		1 sec	NA	NA
16. Hydraulic System Press. Discrete		1 sec	NA	NA
17. EGT		2 sec	TBD; Time over this threshold to be recorded	20°F
18. Longitudinal cyclic Position		2 sec	Somewhere between 3° and 5°	1°
19. Lateral Cyclic Pos.		2 sec	3° and 5°	1°
20. Collective Pos.		2 sec	10-20% of Control	2%
21. Tail Rotor Control		2 sec	10-20% of Control	2%
22. Vert. Accel. Flight Range		low enough for peak and duration for normal flight	2-3g levels	± 0.5 g's
23. Longitudinal Accel. Flight Range		"	"	"
24. Lateral Accel. Flight Range		"	"	"
25. Vibration		2 sec	TBD	TBD
26. Rad Alt		TBD	TBD	TBD
27. PLA		TBD	TBD	TBD

* For those candidate systems where preprocessing may be used.

Other parameters considered are radar altitude and throttle position. Radar altitude would be usable if it were already available; its use may allow the use of the existing low resolution barometric altitude output. Throttle might be valuable to distinguish power changes that were crew initiated from those due to engine problems.

The sampling intervals, thresholds, and accuracies shown in Table 4 are preliminary. Some adjustments will be necessary based on actual flight data and further analysis.

3.2 ENVIRONMENTAL REQUIREMENTS AND GOALS

A crash data retrieval system is unique in that it potentially has two sets of environmental requirements. It has the normal operational environmental requirements that are necessary for aircraft electronic equipment and additional environmental requirements for the survival of the memory portion of the system in a crash and the after effects of the crash. Also, measurement of data during the crash event places added mechanical integrity requirements on certain system elements.

Operational Environment

The design goal for the system is to meet the same operational environmental requirements as other electronic equipment on military helicopters. For example, the UTTAS requirements are MIL-E-5400M Amendment 2, Class 1A. Some of the more significant requirements are summarized in Table 5.

Crash Environment

A crash recording system usually requires extra degrees of survivability with regard to the data storage media. For devices applied to commercial transport aircraft the survivability of the storage module is defined by FAR 37.150, TSO-C51a.[5] See Table 6 for a summary. This document defines shock, piercing loads, crash resistance, thermal exposure and immersion as functions of time to insure a certain degree of survivability.

The degree of survivability and the probability of occurrence of severe Army helicopter mishaps (severe can be interpreted as meaning main fuselage structure breakup and/or fire) must be traded off against the delta cost and weight penalties associated with extra survivability protection. To provide two reference points, the selected systems were defined for the normal Mil level environment as one design goal and by imposition of a modified TSO-C51a as the second design goal on the

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[5] U.S. Federal Aviation Regulation, Part 37.150, AIRCRAFT FLIGHT RECORDER TSO-C51a.

TABLE 5. SUMMARY OF MIL-E-5400M CLASS IA FOR HELICOPTERS

Altitude	0 to 30,000 feet	
Temperature	Continuous operation	-54°C to +55°C
	Intermittent	30 min at +71°C
	Non-operating	-60°C to +85°C
Vibration	20 to 33 Hz	2 g
	52 to 2000 Hz	5 g
Shock	Operating	15 g for 11 msec
	Mount (Crash Safety)	30 g for 11 msec

TABLE 6. SUMMARY OF MAJOR CRASH SURVIVAL REQUIREMENTS OF TSO-C51a

Impact	1000g half sine for 5 msec
Penetration	500 lb weight dropped from 10 feet on 0.05 square inch area.
Static crush	5000 lb continuous
Fire	1100°C on 50% of outside area for 30 minutes if near fuel tanks, 15 minutes if not near fuel tanks.
Water	Immersed in sea water for 36 hours.

storage module. The delta cost and weight between the two were considered versus the percentage of mishaps where the system storage media would not survive.

An additional survivability design goal that is addressed herein is the need for system functional survivability through the initial crash impact for up to 5 seconds. From a structural point of view, certain elements of the system should be capable of survival through the acceleration peaks up to 150 g's in any axis with a 10-msec duration, assuming there is no need to measure impact forces above these values. Since the standard for military hardware is 15 g's, 11 msecs operating, an additional mechanical design burden is imposed on the hardware, which is evaluated in terms of cost and weight.

Equipment built to TSO-C51a requirements have a good record of preserving data. In a study [6] of these systems installed in commercial jet transport aircraft during the period 1960 to 1973 recovery of data was completely precluded in only 6 out of 503 cases (1.2%). Only one of these happened in the 301 cases that occurred after the flight recorders were relocated as far aft in the fuselage as practicable (0.3%). A summary of the cases where complete or partial damage to the recording media caused some loss of data is given in Table 7. This data is for foil type recorders.

Experience is still limited on the new digital flight data recorders that are used on wide body aircraft. However, in the cases where there has been an accident and data was processed, there has been no loss of data due to damage of the recording medium. There has been some data loss due to electronic system failure prior to mishaps with one particular manufacturer's equipment. These can largely be precluded in the future through a more comprehensive built-in test.

The TSO requirements appear to be adequate for jet transport aircraft. Some differences in survivability such as immersion for up to four weeks and longer burning post-crash fires are considered further on in this study. The alternative as discussed above is no special crash protection at all. For aircraft with an improved crash-resistant fuel system, the probability of post accident fire has been greatly reduced. Coupled with this is the fact that in a majority of Army helicopter accidents the main fuselage is intact.

Thus the probability of losing data with no unusual protection may be acceptably low and may be the preferred choice if the cost of protection is too high.

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[6] National Transportation Safety Board, Special Study, FLIGHT DATA RECORDER READOUT EXPERIENCE IN AIRCRAFT ACCIDENT INVESTIGATIONS, 1960-1973, May 14, 1975.

TABLE 7. SUMMARY OF COMMERCIAL DATA LOSS EXPERIENCE

TYPE OF DAMAGE	INITIAL LOCATION	RELOCATION AFT
Mechanical Only	6	5
Fire Only	2	0
Mechanical and Fire	2	1
	10 (of which 6 resulted in complete data loss)	6 (of which 1 resulted in complete data loss)
Total cases	202	301

Survivability can also be greatly enhanced by the choice of location of the system elements. It should be located as far from fuel tankage as possible, in a location that has been shown to be where damage is minimum. The system should not be located in the tail cone, which in many cases separates from the aircraft's main fuselage before the highest impact accelerations of the crew compartment are recorded.

Operational Requirements

The specification of an accident data retrieval system must include more than just the requirements for the airborne equipment inself. All aspects of the total problem must be considered including maintenance of the equipment; repair or replacement of equipment; and retrieval, processing, and interpretation of the data.

Built-In Test (BIT)

The first step is to ensure that data will be available when needed in an effective continuous BIT system. An AIRS system is unique in the sense that it does not have any external effect that would be noticed in normal aircraft operation. The purpose of this equipment is to passively collect data. Without BIT it may only be known whether or not the system is performing its function after a mishap when data readout is attempted.

The self test should indicate the proper operation of the basic system and to the extent practical any sensors that would not be otherwise checked. The system should provide a signal that would be used to provide a proper display to the crew to indicate that the system is not functioning. For example, one master signal would light a fault light

on an advisory panel. On the primary unit itself, latching indicators could indicate whether it or one of the sensors is at fault.

Reliability and Maintainability

The reliability goal established during the course of this study was 5000 hours MTBF on a system level. Also a design goal, as given by the Army, is the elimination of any required periodic maintenance such as replacement of tape and cleaning of recording heads on conventional recording mechanisms.

Design Life

A required Army feature is a design life of 5,000 hours. Any electronic portions of the airborne part of AIRS can meet this criterion based on past experience in the electronic industry.

For sensors that are peculiar to AIRS (not shared by other existing aircraft systems) there may be a trade-off between an imposed 5,000 life and cost to the Army. The lowest cost sensor output devices generally are potentiometers. Potentiometers may be used in the accelerometers, the vernier pressure altitude sensor, and for control position measurement in the interest of lowest installed cost. These devices do have physical sliding contacts and exhibit physical wear primarily in proportion to the number of operating cycles. Alternatively, noncontact sensor device outputs can be had in all of the above sensor types but only at a substantial sensor cost penalty. The cost of the AIRS unit itself would also increase since these alternative sensor output devices employ an AC signal which requires additional signal conditioning circuitry.

Data Retrieval Requirements

The system should be designed so that data can be removed and entered into existing Army data systems as conveniently and inexpensively as possible. A provision is needed to read data out in two different situations: (1) when the unit is apparently damaged and (2) when the unit appears undamaged.

In the case of a major accident, the equipment may be damaged and it would be treated as such. The data is also very valuable and thus great care is required to assure that no data is lost. The total AIRS unit should be removed from the aircraft and sent to a facility where the data can be removed. In some cases the memory module may need to be removed from the AIRS unit and attached to a readout unit that provides all necessary signals for operating the memory. For example, fire may have partially destroyed the AIRS unit except for the thermally protected memory module. A shop level unit as used for major accident data readout would be required at one location only.

It is desirable that the data from an accident information retrieval system be used to investigate minor mishaps also. The readouts for minor accidents and mishaps will be more numerous than for serious accidents, possibly by a factor of ten or more. Thus, it is necessary that data be read out in these cases with minimum cost and inconvenience at the line organization. A portable ground readout unit could be attached to the system and extract the data without it being necessary to remove the airborne unit from the aircraft. In this case the readout unit can be simple because the normal memory interface circuits can be used in the on-board hardware. The readout unit would store data in some form, such as a tape cassette. The data would then be transmitted by telephone line back to a processing center. The tape might also be sent and kept as a backup and permanent record.

4.0 ANALYSIS OF AVAILABLE EQUIPMENT TECHNOLOGY

4.1 AVAILABLE SENSOR SIGNALS IN EXISTING AND NEW AIRCRAFT

The first step in determining the feasibility of developing an economical data retrieval system is to establish how many of the desired parameters are already on the aircraft and are available for use as electrical signals. If most of the parameters are already available in a form that can be used, the expense of adding many new sensors is avoided. Hamilton Standard surveyed four helicopters: two representing current equipment and two representing new helicopters that are expected to come into the inventory in the next few years. The current helicopters reviewed were the Bell UH-1H and the Boeing CH-47. The new helicopters for which data was collected were the Sikorsky UTTAS and the Hughes AAH.

Hamilton Standard sent questionnaires to the manufacturers of each of these helicopters. The information desired for each of the parameters was:

1) The availability of the signal

2) The type signal

3) The signal range

4) Accuracy

5) Dynamic characteristics

6) Any additional comments

The results of this survey are given in Tables 8 through 11. As would be expected, the newer helicopters have more of the required signals available. However, the difference is not as large as might have been expected. Acceleration sensors are needed on all helicopters, and over half of the sensors are available on the least-equipped current helicopter. Some of the more important aspects of each of the parameter lists are discussed in the following paragraphs.

The UH-1H series helicopters have a majority of the required signals. The major signals missing are airspeed, accelerations, and control positions. Also, altitude is only available as the digital code for use in the altitude reporting transponder. This code has a resolution of 100 feet, which does not provide as good a resolution as would be deemed necessary for accident investigation. Possible alternatives for altitude measurement are given in the following section.

The information available from Boeing was for the upgraded YCH-47D. This helicopter is very well equipped. The only missing signals are accelerations and one control position. Some of these signals, such as altitude, may not be available on the current CH-47 A/B/C helicopters. The present altitude accuracy appears to be marginal for use by AIRS.

TABLE 8. SIGNALS AVAILABLE ON UH-1H

Parameter	Signal Available Number	Signal Type	Signal Range	Accuracy	Comments
1. Airspeed	No	Synchro	0-360°		ASN-43
2. Heading	Yes (1)	Discrete	0-31,000		Digital Code Used in Transponder; 100 ft. Resolution
3. Altitude	Yes (9)			40 feet	
4. Vertical Acceleration	No				
5. Longitudinal Acceleration	No				
6. Lateral Acceleration	No				
7. Pitch	Yes (1)	Synchro	±90°		MD-1
8. Roll	Yes (1)	Synchro	±180°		MD-1
9. Engine Torque	Yes (1)	8-15 V RMS 400 HZ			
10. Rotor RPM	Yes (1)	Frequency 0-335Hz			
11. Engine RPM	Yes (1)	Frequency 0-77 Hz			
12. Fire Detection	Yes (1)	Discrete			
13. Chip Detection	Yes (4)	Discrete			
14. Hydraulic Pressure	Yes (1)	Discrete			
15. Exhaust Gas Temp	Yes (1)	Thermo-couple	32° - 1400°F	±6°	
16. Stick Position Lateral	No				
17. Stick Position Longitudinal	No				
18. Stick Position Collective	No				
19. Directional Pedal Position	No				
20. Radar Altimeter	No				

TABLE 9. SIGNALS AVAILABLE ON YCH-47C

Parameter	Signal Available Number	Signal Type	Signal Range	Accuracy	Comments
1. Airspeed	Yes (1)	DC 0-10 V	40-200KTS	±5%	
2. Heading	Yes (1)	Synchro	0-360°	3.5°	
3. Altitude	Yes (1)	DC 0-10V In Steps	-1000 to 12000 Ft.	±250 Ft.	
4. Vertical Acceleration	No				
5. Longitudinal Acceleration	No				
6. Lateral Acceleration	No				
7. Pitch	Yes (1)	Synchro	1°		
8. Roll	Yes (1)	Synchro	1°		
9. Engine Torque	Yes (2)	DC 0-70V	0-150%	±2%	
10. Rotor RPM	Yes (2)	Frequency UNK			
11. Engine RPM	Yes (2)	Frequency 0-70 Hz	±2%		
12. Fire Detection	Yes (1)	Discrete			
13. Chip Detection	Yes (2)	Discrete			
14. Hydraulic Pressure	Yes (1)	Discrete			
15. Exhaust Gas Temp	Yes (2)	Thermocouple			
16. Stick Position Lateral	Yes (1)	AC ±5V	0-100%	±3%	
17. Stick Position Longitudinal	Yes (1)	AC ±5V	0-100%	±3%	
18. Stick Position Collective	No				
19. Directional Pedal Position	Yes (1)	AC ±5V	0-100%	±3%	
20. Radar Altimeter	Yes (1)	DC 0-14V	0-2000ft	2ft or 2%	

TABLE 10. SIGNALS AVAILABLE ON SIKORSKY UTTAS

Parameter	Signal Available (Number)	Signal Type	Signal Range	Accuracy	Comments
1. Airspeed	Yes (1)	Potentiometer 5K ohm	40-200KTS	±5%	Conrac 451318
2. Heading	Yes (1)	Synchro	0-360°	1°	AN/ASN-43
3. Altitude	Yes (9)	Discrete	-1000 to 20,000	50 ft.	Digital Code Used in Transponder; 100 ft. Resolution
4. Vertical	No				
5. Longitudinal Acceleration	No				
6. Lateral Acceleration	Yes (1)	DC + 7.5V		1.0G	Range too limited for AIRS
7. Pitch	Yes (1)	Synchro			
8. Roll	Yes (1)	Synchro			
9. Engine Torque	Yes (2)	DC 0-7V	0-150%	±2%	
10. Rotor RPM	Yes (1)	Frequency 0-11 KHz	0-150%		
11. Engine RPM	Yes (2)	Frequency 0-2556 Hz	0-120%		
12. Fire Detection	Yes (2)	Discrete			
13. Chip Detection	Yes (2)	Discrete			
14. Hydraulic Pressure	Yes (3)	Discrete			
15. Exhaust Gas Temp	Yes (2)	Thermocouple	0-950°		
16. Stick Position Lateral	No				
17. Stick Position Longitudinal	Yes (1)	DC ±7V	0-100%		
18. Stick Position Collective	Yes (1)	DC + 6.5V	0-100%		
19. Directional Pedal Position	No				
20. Radar Altimeter	Yes (1)	DC 0-10.5V			GFE APN-209

TABLE 11. SIGNALS AVAILABLE ON HUGHES AAH

Parameter	Number	Type	Range	Accuracy	Comments
1. Airspeed	Yes (1)	DC 0-10V	0-200KTS	5%	
2. Heading	Yes (1)	Synchro	0-360°	1°	
3. Altitude	Yes (1)	DC 0-10V		5%	
4. Vertical Acceleration	No				
5. Longitudinal Acceleration	No				
6. Lateral Acceleration	Yes (1)	DC ±10V		1%	Range too limited for AIRS
7. Pitch	Yes (1)	Synchro		1°	
8. Roll	Yes (1)	Synchro		1°	
9. Engine Torque	Yes (2)	DC 0-8V		1%	
10. Rotor RPM	Yes (1)	Frequency	1348 Hz= 100%	1%	
11. Engine RPM	Yes (2)	Frequency	1333 Hz= 100%	1%	
12. Fire Detection	Yes (1)	Discrete			
13. Chip Detection	Yes (1)	Discrete			
14. Hydraulic Pressure	Yes (1)	Discrete			
15. Exhaust Gas Temp	Yes (2)	Thermo-couple			
16. Stick Position Lateral	Yes (1)	DC ±10V	±4.5 in.	1%	From SAS
17. Stick Position Longitudinal	Yes (1)	DC ±10V	+5 in.	1%	
18. Stick Position Collective	Yes (1)	DC ±10V	±6 in.	1%	
19. Directional Pedal Position	Yes (1)	DC ±10V	±4.5 in.	1%	
20. Radar Altimeter	Yes (1)	DC 0-10V	0-1500Ft.	5%	

The Sikorsky UTTAS is also well equipped. The only signals missing are three channels of acceleration and two control positions. A channel of acceleration is available but does not cover the impact acceleration range. The UTTAS also has only the transponder output for altitude. The altitude sensor discussion which follows will also apply to this helicopter.

The Hughes AAH is the best equipped helicopter considered. All parameters are available except for three channels of acceleration. An accelerometer is available on the AAH, but it also does not cover the impact acceleration range.

4.2 NEW SENSORS

Up to four new different sensor types would have to be added to the four helicopters surveyed to give them the capability to provide the full recommended parameter list. These sensors are for altitude, airspeed, acceleration. and control position. The technical and cost impacts for adding these sensors are discussed in the following paragraphs.

Altitude

The transponder code is available on all helicopters. However, this code has a resolution of only 100 feet, which is marginal for analyzing the details of an accident. There are at least two alternatives for improving the resolution. One is adding a new altimeter which provides an output with an improved resolution and the second is the addition of a new pressure transducer.

Altimeters could be modified by two different methods to provide an improved altitude output. One possible way would be to modify the code output. The standard code consists of eleven signals, providing for a full altitude range up to 50,000 feet. Since helicopters do not use this full altitude range, two signals could be redefined to give a possible resolution of 25 feet. It may also be necessary to modify the gearing to give the necessary resolution on the digital encoder. The nonrecurring engineering to modify and requalify an altimeter such as the AAU-32 is expected to be $100,000 to $150,000. The new price is expected to be $100 to $300 more than the current altimeter. Modification of current altimeters would cost $200 to $400. The total cost would thus be $200 to $500 for new helicopters and $300 to $600 for retrofit installations.

The other possible altimeter modifications would be to substitute a low-torque synchro or resolver for the digital encoder. This modified altimeter would thus replace the second altimeter. The nonrecurring cost is expected to be somewhat less, approximately $75,000 to $100,000. The recurring cost is expected to be at least $2500. This altimeter would replace the nondigital output altimeter such as the AAU-31, which cost approximately $1,500. Thus, the incremental cost is at least $1,000 per helicopter.

An alternative to the modification of an altimeter is the addition of a separate pressure transducer to provide an output for the flight data system. The accuracy and sensitivity of the pressure transducer needs to be roughly equivalent to the primary altimeter. Several transducer vendors were contacted, and the minimum cost for transducers of this quality is expected to be in the range of $600 to $1,000. If the output of the transducer is an analog voltage, this voltage must be converted with an accuracy of at least 0.1% to give the required 20-foot resolution. This conversion accuracy would require an analog-to-digital converter with at least 10 bits. Altitude would then be the only signal that requires more than eight bits. The expense of the transducer and the corresponding added complexity of the input interface makes this approach undesirable.

An alternative approach is a hybrid one that uses the transponder code that exists on all helicopters in conjunction with an additional transducer. The transponder code would give the altitude to within a resolution of 100 feet that is as accurate as the primary altimeter. The absolute accuracy of the added transducer would not be critical. It would only be important that this transducer provide the necessary resolution between 100-foot increments of the transponder code. The added transducer would, in effect, be calibrated everytime the aircraft passed through a 100-foot increment. The transducer survey showed that a sensor with these requirements could be obtained for $150 to $250 in large quantities. Major characteristics of a particular transducer that can be obtained for less than $200 are shown in Table 12.

TABLE 12. ALTITUDE SENSOR CHARACTERISTICS

Type:	Silicon-diffused diaphragm
Excitation:	10 to 30 volts DC, unregulated
Full-Scale Output:	5.0 VDC $\pm$0.25 VDC
Zero Offset:	Within +5% -0% FS
Accuracy:	1.25% FS for -18°C to +65°C
Operating Temperature Range:	-55°C to +125°C
Vibration:	20g rms 5 to 2000 Hz
Acceleration:	40g
Size:	1.5" X 1.5" X 2.0"
Weight:	12 Oz.

The output of the transducer is a bridge which will give essentially infinite resolution. It is assumed that good resolution of altitude will be needed up to 10,000 feet. The conversion accuracy to obtain the desired 20-foot resolution will require nine bits. A nine-bit A/D converter can be avoided by having an offset voltage that is switched to provide two 5000-foot ranges. The switch for the proper range is provided by the known altitude from the transponder code input. This hybrid approach was judged to be most cost effective and is used in the subsequent analysis. The fine resolution is already available on the Hughes AAH helicopter and would have to be added on the other three candidate helicopters.

A final alternative may be to use the radar altimeter and the coarse resolution barometric altimeter output and not provide a baro-altitude vernier transducer as described above.

Three out of four of the helicopters surveyed are equipped with radar altimeters. The vast majority of accident scenarios start well below the radar altimeter range. Above the maximum range, the altitude transponder 100-foot resolution increments could be acceptable. A radar altitude return signal would be lost in some cases, however, due to possible high pitch and roll motions that could be part of the accident scenarios.

Airspeed

An adequate airspeed signal is available for three of the four helicopters considered. A separate transducer must be added to the UH-1 to provide the airspeed signal. This transducer must be differential with a range of 0 to 1 psi. It should have an accuracy of 1% or less. A transducer that would be adequate for these requirements is expected to cost from $400 to $500 in quantity. The characteristics of a particular transducer considered are shown in Table 13.

TABLE 13. AIRSPEED SENSOR

Type:	Capacitive
Input Voltage:	28 VDC
Output:	0 to 5 VDC
Nonlinearity	$\pm$0.1% FS
Temperature Effect:	$\pm$ (0.5% FS + 0.25% recording) at -18°C and +65°C
Operating Temperature Range:	-54°C to 93°C
Vibration:	10 g's 5 to 2000 Hz
Size:	3.6" X 1.2" X 1.2"
Weight:	7 Oz.

Acceleration

In evaluating the acceleration sensor requirements for the AIRS system, several considerations were addressed. These considerations included sensor range, accuracy, response, sampling rates, and dynamic response due to vibration. The principal sensor range and accuracy requirements are shown in Table 14. The range and accuracy requirements are considered to be design goals. The requirement for maximum range, particularly for impact, depends to some extent on the location of the sensor. A specific definition of the requirement would depend on the particular helicopter and particular location.

For example, on the UH-60A, the suggested accelerometer location for measurement of impacts may be on the main floor just aft of the crew seats and over the landing gear. This location is in an area where structural deformation will be minimal at or above the floor level for all but the most severe accidents. Hence the value of max g's and durations measured can be estimated to be the same at other nearby locations with no extrapolation required.

Human survivability measurements, restraint systems, and other design criteria for restraining objects in cabin areas generally fall within the 100 g range. Another important reason for considering a limitation on max impact g's to near 100 g's is that measurements of forces as the result of (or input to) such things as energy-absorbing landing gear and crew/passenger seats are around 10 g's. 10 g's is above the desired flight g range. The flight g range is $\pm$ 5 g's max vertical, and less in the other axes. Hence, desired measurements around 10 g's may have to be made in the impact g sensor channel.

Examination of available impact data, where at least a major portion of the main fuselage of a helicopter remained intact, indicates shock impulses in excess of 120 g's with a 10-ms half sine wave response[7]. It appears that the maximum g range should be approximately 150 g's. While g peaks higher than this are possible, it may be academic to employ higher range devices since the AIRS as a system and its supporting power source may not remain intact. To insure adequate sensor response, the damping ratio should be designed between 0.4 and 0.9 to minimize the "Q" and to provide a flat response at the expected 50 Hz. The availability of such sensors on the present market is examined in the following paragraphs.

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[7] Singley, George T. III, FULL SCALE CRASH TESTING OF A CH-47C HELICOPTER 32nd Annual National V/STOL Forum, American Helicopter Society, May, 1976.

TABLE 14. RANGE AND ACCURACY REQUIREMENTS FOR ACCELERATION RECORDING

	RANGE	DESIRED ACCURACY	MINIMUM ACCURACY
Flight Accelerations			
Vertical	±3g	±0.2g	0.5g
Lat. & Long.	±1g	±0.05g	0.5g
Impact Accelerations			
All Axes	±150g	±0.5g	±1.0g

A market survey was made to evaluate and determine existing accelerometer sensors that meet the requirements established for both flight acceleration and impact acceleration monitoring. The study also included that class of sensors requiring only slight modifications to meet these requirements. The basic criterion for selection was a performance/cost trade-off. Of primary concern in establishing the performance requirements was the necessity of monitoring/impact accelerations. It is desirable to have one sensor to accomplish both measurements from a cost point of view. In order to maintain the accuracy requirements, the sensor should be of a nonlinear nature implying a constant accuracy-to-input ratio. A sensor of this type was not found to be immediately available. The development of such an instrument is based on a nonlinear spring-mass configuration, and for this particular application, it is felt to be cost-prohibitive. An alternate, and more satisfactory configuration is the dual triaxial cluster where one triaxial is scaled to measure the sustained flight accelerations, and the other is scaled to measure the impact accelerations. After discussions with the Army preparatory to starting Phase II it was decided to drop the flight g measuring requirements longitudinally and laterally and retain only the vertical flight axis. There are a wide range of accelerometers on the market that may be scaled to accomplish these measurements with the minimum accuracy requirements. The most likely candidates are shown in Table 15. Of these five accelerometers, two are of the AC/AC Linear variable differential transformer type requiring output AC signal demodulation. This demodulation, although simple, adds increased cost on a high-production basis, with the requirement of four per system. A comparison of the accuracy gained with this type of sensor does not warrant the increased cost. Also a factor in the selection of an accelerometer type is operating life. The Army requirement for a 5,000-hour life may not be achievable. It should be noted this is equivalent to airborne operating hours where the pickoff wiper is being exercised. Utilization of AC pickoffs would provide the desired life at a 66% cost increase per sensor, in addition to a small cost increase in the AIRS unit (5% typical). The overall effect on AIRS system cost in using AC type accelerometer pickoffs instead of DC potentiometers is a price increase of 10 to 15%. In view of the paramount need to minimize costs, the AC pickoff accelerometers are not recommended.

TABLE 15. ACCELERATION SENSOR CHARACTERISTICS

MODEL	TYPE	SIZE (IN.)	WT. (oz.)	RANGE	TOTAL ACCURACY	INPUT/ OUTPUT	COST ($)
Bell & Howell Type 4-204	Tri-Axis	2.2 x 2.3 x 1.8	7	±5 → ±500	± 2%	5VDC/DC	200 (each axis)
* EDCLIFF Submin. 7-101	Single-Axis	1.25 x 1.25 x .78	1.5	±5 → ±100	± 1.5%	DC/DC	150
EDCLIFF Min 7-114	Single-Axis	1.84 x 1.14D	2.5	±2 → ±100	± 1.5%	DC/DC	230
Timex Model AP-000	Single Axis	2-3/8 x .94D	4	→ ±100	1/2Sc → .1%FS FS → 2%FS	AC/AC	~ 250
HS Supergee DC-Out 60 Series	Single Axis	2.3 x 1.0D	4.6	±1 → ± 100	1/4S → .2% 1/2S → .5% FS → 2%	AC/AC DEMOD.	~ 250

* The manufacturer claims that this unit can also be provided with a ± 150g range with the same characteristics.

The particular sensor used as a baseline in this study from the three linear potentiometer accelerometers of Table 15 is the EDCLIFF Subminiature Model 7-101. This instrument meets the specified accuracy requirements and, on a large-scale production basis, is priced at approximately $150. General features of this instrument include optional ranges from $\pm 5g$ to $\pm 100g$ with a total static error band of 1.5%. This sensor does not presently meet the full-range goal of 150 g's. However, its range could be extended to 150 g's. The instrument may be operated from $-50^{o}C$ to $100^{o}C$ with a varying damping ratio of 0.4 to 0.9. The natural frequency is functionally dependent on the range scaling and may vary from 20 to 110 Hz.

With a maximum static error band of 1.5%, the accuracy of the 5g scaled sensor is 0.075 g's, which is well within the minimum 0.5g accuracy requirement. For the 150g scaled sensor, the static error band would be 2.25g. It must be pointed out, however, that the maximum static error band represents the worst-case accumulation of errors contributed from resolution, linearity, hysteresis, friction, and repeatability. It is felt that the specified static error band is extremely pessimistic and that, for practical purposes, the 1g accuracy requirement in measuring impact accelerations can be approached or met.

The EDCLIFF model 7-101 is a compact instrument weighing only 1.5 ounces and occupying only 1.2 cubic inches of space. Its compactness allows for ease of installation and maintainability in a triaxial block. The single unit for flight and the three units for impact accelerations may be "piggy-backed" into a single cluster or isolated, depending on location requirements.

Control Position Transducers

Control position transducers must be added to most of the helicopters. Two types of transducers were considered. These were a linear variable differential transformer (LVDT) and potentiometer. The LVDT would have a longer life. However, it has the disadvantages of being expensive and having an AC output which would require additional input signal conditioning hardware. These sensors would be linear or rotary, depending on the most convenient linkage arrangement. The same life considerations apply for AC versus DC pickoffs as discussed for the accelerometers above.

Consolidated Parameter List

The combined parameter signal list for all helicopters considered including the assumed new sensors is given in Table 16. This total signal list established the requirements for the input interface circuits for the proposed systems. Elapsed time is also a parameter that is generated within the AIRS.

TABLE 16. CONSOLIDATED PARAMETER SIGNAL LIST

	PARAMETER	UH-1H	YCH-47D	UTTAS	AAH
1	Airspeed	0-5V DC*	0-10V DC	Pot	0-10V DC
2	Heading	Synchro	Synchro	Synchro	Synchro
3	Altitude	Discretes (9) 0-5V DC*	Discretes (9) 0-10V DC	Discretes (9) 0-5V DC*	Discretes (9) 0-10V DC
4	Vertical Acceleration	Pot*	Pot*	Pot*	Pot*
5	Longitudinal Acceleration	Pot*	Pot*	Pot*	Pot*
6	Lateral Acceleration	Pot*	Pot*	Pot* ±7.5V DC**	Pot* ±10V DC**
7	Pitch	Synchro	Synchro	Synchro	Synchro
8	Roll	Synchro	Synchro	Synchro	Synchro
9	Engine Torque	8-15V 400 Hz	0-70V DC	0-7V DC	0-8V DC
10	Rotor RPM	Freq. 0-335Hz	Freq. UNK	Freq. 0-11KHz	Freq. 0-1618Hz
11	Engine RPM	Freq. 0-77Hz	Freq. 0-70Hz	Freq. 0-2556Hz	Freq. 0-1600Hz
12	Fire Detection	Discrete (1)	Discrete (1)	Discrete (2)	Discrete (1)
13	Chip Detection	Discrete (4)	Discrete (2)	Discrete (2)	Discrete (2)
14	Hydraulic Pressure	Discrete (1)	Discrete (1)	Discrete (3)	Discrete (1)
15	Exhaust Gas Temp.	Thermocouple	Thermocouple	Thermocouple	Thermocouple
16	Stick Position Lateral	Pot*	±5V AC	Pot*	±10V DC
17	Stick Position Longitudinal	Pot*	±5V AC	±7V DC	±10V DC
18	Stick Position Collective	Pot*	Pot*	±6.5V DC	±10V DC
19	Directional Pedal Position	Pot*	±5V AC	Pot*	±10V DC
20	Radar Altimeter	N/A	0-14V DC	0-10.5V DC	0-10V DC

* New Sensor

** Existing sensor for flight acceleration

4.3 SIGNAL HANDLING HARDWARE

The following paragraphs discuss the implementation of signal-conditioning devices in general terms. Details of the specific functions of the various signal conditioning, multiplexing, etc., are covered in Section 7 of this report.

The chosen components as outlined in the following paragraphs were used to obtain a rough size, weight, and cost estimate for various system approaches that were traded off.

Signal conditioning can be provided with present-day technology using various levels of integrated circuit technology (i.e., Large-Scale Integration (LSI), hybrid technology).

In general, cost/performance will be optimized when piece/part electronic component integration is at the level where many diverse applications use the same integrated circuit. This makes the total market for the device large and the competition intense. This large volume and competition results in quality building block Integrated Circuits (IC's) at a reasonable price. Using less than the available level of integration is obviously less than optimum since it tends to increase end product cost due to higher labor content and because of the increased piece/part costs themselves. Unit size and weight are also unfavorably affected. Going to more than the marketplace-established level of integration tends to rapidly increase the end product price since custom designs are required. While unit size and weight are further reduced by providing a further measure of integration, the price increase per pound saved, in many cases, cannot be justified.

The advent of bipolar Integrated Injection Logic (I^2L) technology has produced a device which may, in the future, make custom LSI more feasible from a cost viewpoint. A new type of device is appearing which combines linear devices and digital circuits on one monolithic chip. This device contains resistive elements and logic gates that may be mask-interconnected to perform only logic or complete custom analog to Transistor-Transistor Logic (T^2L) or I^2L to analog functions. Exar Integrated Systems Inc. calls this type of device a "Master Slice", which they are offering with 256 4-input NAND gates and 200 bipolar devices that may be custom interconnected with any configuration. International Microcircuits Inc., Interdesign Inc., TRW and others are offering similar "customable" devices[8]. Application to AIRS for digitization of input frequencies may prove to be a cost-effective device. For present design trade-offs, however, use of custom linear/digital devices have not been assumed. While further customization appears cost effective some time in the future, at least for certain types of circuit functions, as is reported further on in this report, the size and weight goals established appear to be approachable with the degree of integration available today.

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8 ELECTRONICS REVIEW - SOLID STATE, Electronics, May 27, 1976, Page 42.

A survey of the market yields a host of very powerful integrated circuits available over full military temperature range from multiple sources, which can be readily used as building blocks for providing desired signal conditioning. Included are the following:

A) Quad amplifiers - four high-performance amplifiers are contained in a single 16-pin Dual In-line Package (DIP).

B) Quad analog switch - four isolated analog switches with built-in level translators are provided in a single 16-pin DIP.

C) Eight-and 16-way analog multiplexer - multiplexers are available with built-in address decoding in 16- and 28-pin DIP's, respectively.

D) Phase locked loops - 16-pin DIP chips are available for phase locking on input signals

E) Quad comparers - four high-impedance devices with T^2L compatible outputs are available in 16-pin DIP's.

F) Dual quad multiplexer - discrete multiplexer chips are available in 16-pin DIP packages

G) Eight-bit Analog-to-Digital (A/D) converter - a successive approximation A/D Complimentary Metal Oxide Semiconductor (CMOS) technology chip with built-in ladder and timing is available in a 22-pin DIP.

With these building blocks for analog signal conditioning, digitization, discrete signal conditioning, and multiplexing can be readily provided. In general, passive components used with the above devices (i.e., resistors and capacitors) are fabricated using fairly mature technology. Therefore, major changes in passive components are not anticipated. Some gradual improvement in reliability may be seen due to improvements in manufacturing processes used in AIRS, where combining into a network is not practical because of circuit layout. Discrete resistors continue to improve in accuracy and temperature stability although in some circuit areas a favorable cost, size, and weight trade-off exists for using integrated resistor networks. Two major technologies under which resistor networks are fabricated are thick and thin film.

A thin-film resistor network is fabricated by vacuum-depositing a metal-based resistive film on a substrate. This process yields a network with accurate absolute values of resistance and even tighter control of resistance ratios. Since the resistance film is vacuum-deposited, the film is distributed uniformly over the substrate, and very uniform temperature coefficients are obtained. The resistance ratios of the network, therefore, show very little change due to temperature variations.

Thin-film networks have a relatively long turn-around time, a fairly high set-up cost, and are more expensive to produce than thick-film networks. Thin-film networks are most cost effective where accuracy and close resistance ratio tolerances are required for a large quantity of units.

A thick-film resistor network is fabricated by screening a resistance paste onto a substrate and firing the network to cause adhesion of the paste to the substrate. This process yields a network with reasonable absolute resistance tolerance and good resistance ratio tolerance. The temperature coefficient of resistance ratio is also fairly good.

Thick-film networks are cost effective in moderate volume usage, since set-up and production costs are moderate. Custom thick-film networks can be used cost effectively in AIRS where a number of identical circuits are required and PC board layout is conducive to their use. In general, in AIRS the accuracy of thick-film networks is felt to be adequate and therefore favors their use.

Discrete ceramic or mylar capacitors can be used for filtering as required to limit bandwidth or to provide analog signal ripple reduction. Use of this approach allows easy alterations for various applications of AIRS without major redesign. More detailed discussion of the implementation of the various forms of signal conditioning is included in Section 7.0.

4.4 DATA PROCESSING HARDWARE

The activity in the industry in the microprocessor area is at a high level with many digital vendors producing at least one type. There are basically four types of microprocessors which are expected to become industry standards: the single-chip, 4-bit microprocessor, the 8-bit microprocessor, the 16-bit microprocessor, and the bit-slice devices.

The single-chip 4-bit units are generally slow P-Channel Metal Oxide Semiconductor (PMOS) processors which contain mask-programmable Read Only Memory (ROM) and Random Access Memory (RAM) in limited quantities on the chip. They are truly one-chip computers intended for the simple problems with high volume production. These devices will be available with alterable ROM on the chip in the future.

The most popular type of microprocessor is the 8-bit N-Channel Metal Oxide Semiconductor (NMOS) unit. While they are billed as single-chip processors, they generally require the addition of a number of memory and input-output support devices before useful functions can be accomplished. They have fairly extensive instruction sets and two microsecond 8-bit add times, but generally do not have hardware implemented to multiply or divide. The most popular 8-bit processor today is the 8080, which is available from at least five sources. It is also available over the military temperature range from at least two vendors. With the improvements of NMOS technology it is expected that the speed of these processors will increase by a factor of two over the next two years, and the number of support chips required will be reduced.

The 16-bit processor chips operate on 16-bit data words and are therefore better suited for most control system problems. Again, today's 16-bit processor chips require the addition of memory and support devices before useful functions can be accomplished. Some of the 16-bit processor chips have hardware multiply and divide, enabling them to execute a 16-bit multiply in 17 microseconds. It is expected that NMOS will become the primary 16-bit technology, and the 2:1 speed improvement projection also applies.

The bit slice processors are available in either 2-bit or 4-bit units which can be cascaded into a processor of any desired word length. Since they are generally used to design or emulate processors in the minicomputer class, low-power Schottky T^2L (LSTTL) is the primary technology employed. Most of these chips operate in the 6-10 MHz range and can be configured to execute a 16-bit add in 200 nanoseconds.

For AIRS application the 8-bit NMOS unit provides adequate signal processing capability. The 8080 processor family with its complement of Input/Output (I/O) chips was used in the size/cost trade off analysis. More details of the implementation of the processor are included in Section 7.0.

4.5 DATA STORAGE TECHNOLOGY

The technologies available to preserve the data that is collected until it can be extracted falls into two major categories. The first includes all forms of electromechanical recording devices that represent the technology used in current accident data recording systems. The other category is new technology solid-state memory devices which now have the potential for meeting the AIRS requirements.

Electromechanical Recording

Two basic electromechanical recording techniques are presently being used in accident recorders. One is foil-type recording and the other is digital magnetic tape recording. Recorders of both types meet the FAR TSO requirements and are presently being used on commercial and some military aircraft.

A symbolic diagram of a foil type recorder is shown in Figure 2. These recorders operate by engraving the value of the parameter on a metallic foil using scribers. These scribers are actuated by sensor signals from external or internal sensors. Time correlation is provided by a constant rate drive of the foil medium or by a separate time scribe. These systems record at least four parameters. Some models have optional capacity for up to five more. Characteristics of a typical foil recorder are given in Table 17.

The primary advantage of this type recorder is that it is fully developed. However, this type recorder has disadvantages that make it unacceptable for a military helicopter accident recorder application. The unit is excessively large and heavy, records only a minimum of parameters, does not have high reliability because of the large number of mechanical parts, and requires periodic maintenance to replace the foil medium. Both the initial cost and continued cost of foil replenishment appear excessive for small military aircraft.

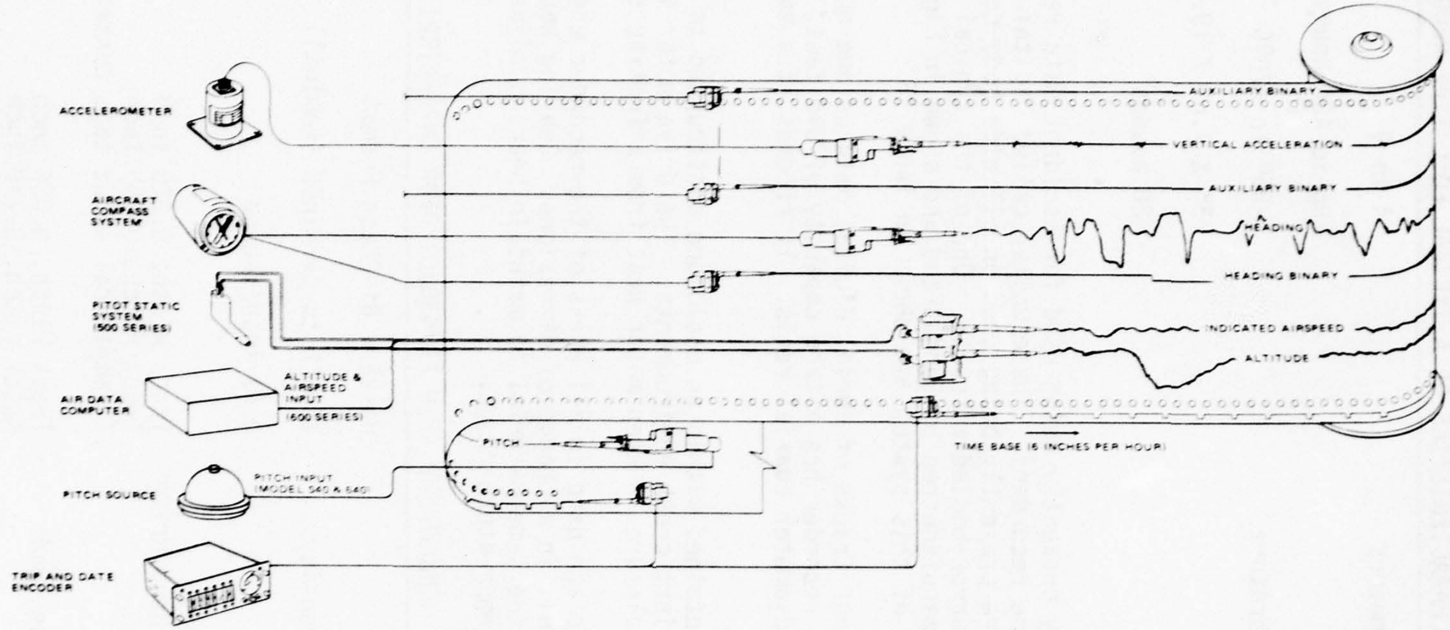

FIGURE 2. FOIL TYPE RECORDING SYSTEM

TABLE 17. CHARACTERISTICS OF A TYPICAL FOIL TYPE RECORDER

Number of Parameters	4 to 9
Recording Time	Up to 400 hours
Operating Temperature	-55° to +70°C
Size	5" X 7.6" X 19.5" (700 Cu. In.)
Weight	20 pounds

The other technology presently being used for accident data retrieval is digital magnetic tape recorders. These units, called Digital Flight Data Recorders (DFDR), are presently being used on all wide-body commercial aircraft and some narrow-bodied aircraft. One of the typical DFDR's now being built is one manufacutred by Sundstrand and shown in Figure 3. The characteristics of this system are shown in Table 18.

This DFDR records four tracks of serial digital data on one-quarter-inch magnetic tape. The recorder has a tape capacity of 810 feet, which is stored on 4.5-inch-diameter coaxial reels. It records at a tape speed of 0.43 ips.

The transport is contained within an enclosure constructed to protect the recording media against crash environments. The drive motor is mounted outside the thermal enclosure to keep motor heat from affecting the transport.

Compatible materials are used in all areas of the recorder where temperature variation might result in a change of dimensions. Bearing housing and shafts are made of the same material to maintain bearing adjustment throughout the operating temperature range.

TABLE 18. SUNDSTRAND (P/N ED743830) DFDR CHARACTERISTICS

Format:	Harvard Bi-Phase Format
Single-Track Density:	1800 bits-per-inch (nominal)
Tape Speed:	0.43 inch/second
Track Position:	
Four-Track Read/Write Heads:	Track Width, 0.030 inch Track Pitch, 0.055 inch (Symmetrical about tape centering)
Two-Track Erase Head:	Track Width, 0.036 inch Track Pitch, 0.110 inch (For interlaced alternate track erase)

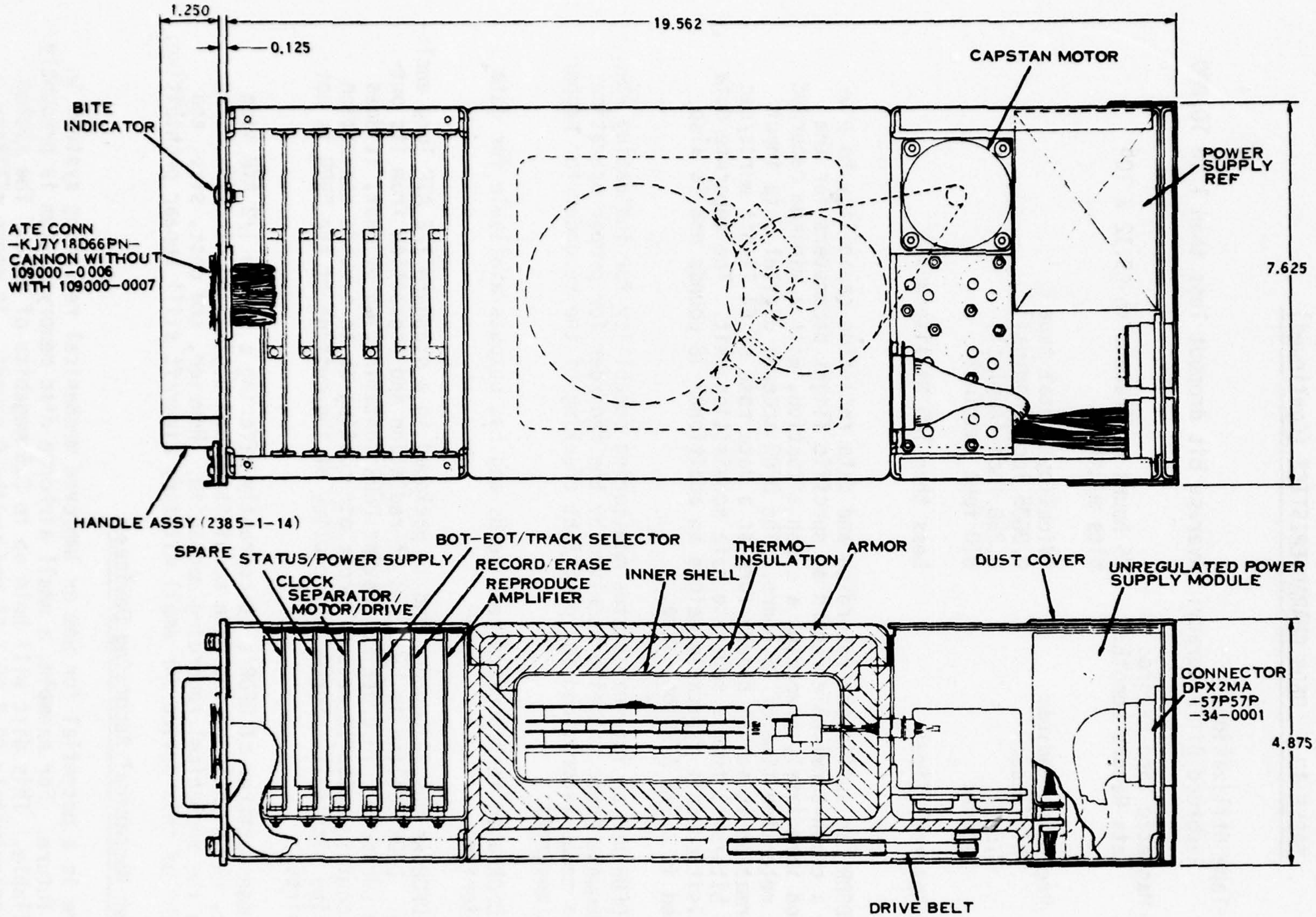

FIGURE 3. DIGITAL FLIGHT DATA RECORDER ASSEMBLY

TABLE 18. DFDR CHARACTERISTICS (Continued)

Tape Utilization:	
Recorded Bit Accuracy:	Average bit dropout less than 1 in 10,000
Magnetic Tape Record:	
Data Record Length:	25 hours equivalent to 69.12 X 10^6 bits minimum
Recording Medium:	"Vicalloy" metal tape
Thickness:	0.0005 inch (nominal)
Width:	0.250 inch (nominal)
Length:	810 feet (nominal)
Reversal Time:	Less than 100 Milliseconds

The DFDR has sufficient recording and data retention capability to provide a crash-survivable record of specific flight parameters for the period immediately preceding a crash situation, with a minimum recorded data retention time of 25 hours. The DFDR accepts digital data input information in serial binary form at a data rate of 64 12-bit words/sec (768 bits/sec) from a separate data acquisition unit. The separate data acquisition unit typically weighs an additional 18 pounds and is also housed in a 1/2 ATR long case.

The DFDR has an internal status monitoring capability for indicating when inadequate power is being received by the recorder for proper operation, and a means is provided for preflight checking of the recorder for proper tape movement.

The DFDR also incorporates read heads and has outputs available for data monitoring.

The DFDR weighs 24 pounds, and is packaged in a standard 1/2 ATR long enclosure. DFDR cooling is by means of radiation and convection from its outside surfaces. In order to prevent DFDR contamination by dust, it does not contain holes to accept forced air cooling or to provide convection cooling within it. Forced air cooling of the outside of the DFDR is not required.

One manufacturer of DFDR's is currently offering a single 1/2 ATR long unit, which includes the data acquisition and digitizing circuits along with the mechanical recording mechanism. However, the cost, size, and weight of this device for small military aircraft still appear prohibitive.

Other Mechanical Recording Devices

There is a potential for new or improved mechanical recording systems in the future. For example, a small airborne disc memory system is presently available. This disc will hold up to 2.5 megabits of data. The system is approximately 9" X 6" X 5" and weighs 9 pounds. It meets military

environment standards, including up to 20 g's acceleration. It has an extremely high bit rate of up to 5 MHz, which greatly surpasses the requirements of the AIRS application. However, at this time it is considered too expensive for the AIRS application, with a possible cost of $7,000 to $10,000. Electronics for signal conditioning, control and digitizing would have to be added to this disc.

There is a possibility of further improvement in current tape systems. However, no major technological changes are known at this time that would have significant cost, size, weight and reliability improvements. Any significant improvements (i.e., greater than a factor of two decrease in size and weight and a factor of two increase in reliability) will only serve to drive the unit cost even higher.

It should also be noted here that recording of crash impact data through 150 g 10 millisecond peaks using electromechanical devices is not feasible. Using these devices, the AIRS would essentially be a flight data recorder only.

Electronic Memory System

Rapid progress has been made during the past ten years in the technology asssociated with solid-state memories. Magnetic core memories made sufficient progress through improvements in the magnetic devices and also improvements in the supporting semiconductor circuits to remain the dominant computer memory technology until about 1974. Magnetic core memories are still temperature-sensitive, heavy, and expensive to use in the candidate recorder. Magnetic plated-wire memories are even more expensive than core memories.

The speed of MOS (Metal Oxide Semiconductor) RAMs (Random Access Memory) has increased and the cost has dropped to the point where MOS RAMs are used in most computer memories designed after 1972. These advances have been possible as a result of the combined effect of improvements in integrated circuit fabrication processes, semiconductor device technology, and memory organizations. Trends established during the past five years indicate that the density of semiconductor RAMS (bits per chip) can be expected to increase by a factor of four about every two and one-half years, and the cost per bit can be expected to drop in half in the same time period.

The semiconductor memory field can be divided into those which are volatile (lose the stored data when power is removed), such as RAM and CCDs (Charge Coupled Device), and those which are nonvolatile, such as ROMs, PROMs (Programmable Read Only) Memory, and EAROMs (Electrically Alterable Read Only Memory). Memory devices used in the accident recorder must be nonvolatile,or a separate battery must be supplied which will prevent the loss of data from a volatile memory. The power dissipation of most types of volatile semiconductor memories is too high to allow a reasonable size battery to retain the information for the desired length of time following the crash, but the power dissipation of CMOS (Complementary Metal Oxide Semiconductor) RAMs is low enough to warrant further consideration. CMOS RAM memories with batteries are being used to provide a nonvolatile memory in a number of commercial microprocessor and instrument systems. This

approach was rejected for the accident recorder application because of the poor maintainability and reliability of a battery under the severe environmental conditions associated with the recorder. Available batteries do not have the required operation and shelf life capabilities for the high and low temperatures to be encountered in this application.

Most of the nonvolatile types of semiconductor memory are not suitable for use in the recorder. Information can be stored in ROMs only during fabrication, and PROMs can be programmed only once. Thus, EAROMs are the only available semiconductor memory devices capable of satisfying the full set of requirements for the recorder memory. Several companies have developed processes for producing an EAROM that uses silicon dioxide and silicon nitride layers as the gate insulation in the transisters in a MOS ROM (Read Only Memory) so that a charge on the gate can be stored and removed electrically. National Cash Register has been successfully producing MNOS (Metal Nitride Oxide Semiconductor) EAROMs for use in their commercial equipment for several years. General Instruments has obtained a license from NCR to also produce these devices. Several companies are interested in obtaining a license, while still other companies are developing their own process. These devices are intended for commercial applications, with operation specified over the 0^{o} to $70^{o}C$ temperature range, and storage with data retention specified over the -40^{o} to $70^{o}C$ temperature range. The devices can be stored over the -65^{o} to $+150^{o}C$ temperature range without damage, and although data retention is not guaranteed over this range, tests [9, 10, 11] have demonstrated that data was not lost during storage for 2000 hours or more at $125^{o}C$. Several [9, 12] military electronic system suppliers have successfully utilized EAROMS produced by NCR in computer and communication systems, and large quantities of EAROMs are now in computer and communication systems, and large quantities of EAROMs are now being produced for use in TV tuners. The microprocessor market for EAROMs is expected to be large, and major effects are being applied to develop units that are reliable, easy to use, and fast.

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9 Collum, Charles E., Wiker, Richard L. and Spence, Wendell, *THE EVOLUTION* OF THE MNOS EAROM AND IT'S APPLICATION TO AVIONICS AND OTHER MILITARY SYSTEMS, NAECON; 76 RECORD-730, 750.

10 Lodi, Robert J., et al, CHIP AND SYSTEM CHARACTERISTICS OF A 2048-BIT MNOS-BORAM LSI CIRCUIT, 1976 IEEE International Solid-State Circuit Conference

11 Beltz, C.A., and Fedorak, R, MNOS BLOCK ORGANIZED RANDOM ACCESS MEMORY SYSTEM DEVELOPMENT, NAECON 1976 RECORD-751, 755.

12 Aldred, E.D., Young, C.R. and Schuermeyer, F.L., TEST RESULTS ON AN MNOS MEMORY FOR RADIO FREQUENCY PRESET APPLICATIONS, NAECON 1976 RECORD-756, 759

Another relatively new memory technology that is just beginning to be used in commercial applications is the Magnetic Bubble Memory. Magnetic bubbles were discovered at Bell Laboratories about 1968. A magnetic bubble is a cylindrical magnetic domain with a polarization opposite to that of the thin magnetic substrate in which it is embedded. Figure 4 shows how the serpentine patterns of magnetic domain shrink to form bubbles as the external magnetic field is increased. The position of bubbles is precisely controlled by depositing a pattern of small magnetic dots on the substrate. Permanent magnets are used to hold the magnetic bias at about 100 oersteds so that bubbles remain stable in size and position without electric power. Figure 5 shows how a rotating magnetic field applied by a pair of perpendicular coils can be used to move bubble positions along a prescribed path. Bubbles can be created and destroyed by applying an appropriate magnetic bias. A pair of magneto-resistors can be used to sense whether a bubble is located in a given position. Prototype wafers that are 0.25 inch on a side are being produced which contain 60K to 100K bits and operate at from 50 KHz to 300 KHz. As of this writing, a one-megabit device is being offered. These units operate over the 0° to 50°C temperature range, and they retain stored data in the nonoperating state over a wider temperature range. Prototype memory systems have been tested satisfactorily for operation over the temperature range of -30° to 80°C and for nonoperating storage over the temperature range of -50° to 100°C.

Thus, the two prime candidates for this application are MNOS EAROMs and magnetic bubble memories. Preliminary studies indicate that use of bubble memories would be advantageous in recorder systems where the required capacity is 100K bits or more, or where the average data rate exceed 1000 bits per second. In addition, the lower cost of bubble memories and a longer life than EAROMs, provide additional incentives for use.

Available EAROMs are limited to 10^5 erase-write cycles, which limits the life of the memory if the data rate is high, while a bubble memory has an unlimited lifetime. However, for AIRS an application of 10^5 erase-write cycles over the life of the EAROMs appears to be adequate when a microprocessor is used to reduce the average data rate. MNOS EAROMs offer the advantage that they can withstand wider temperature extremes, and they require less support circuitry for small systems than bubble memories. The factors of importance for selection of the crash recorder memory technology are: temperature range, cost, size, power, and life. A more detailed discussion of these characteristics of the candidates follows:

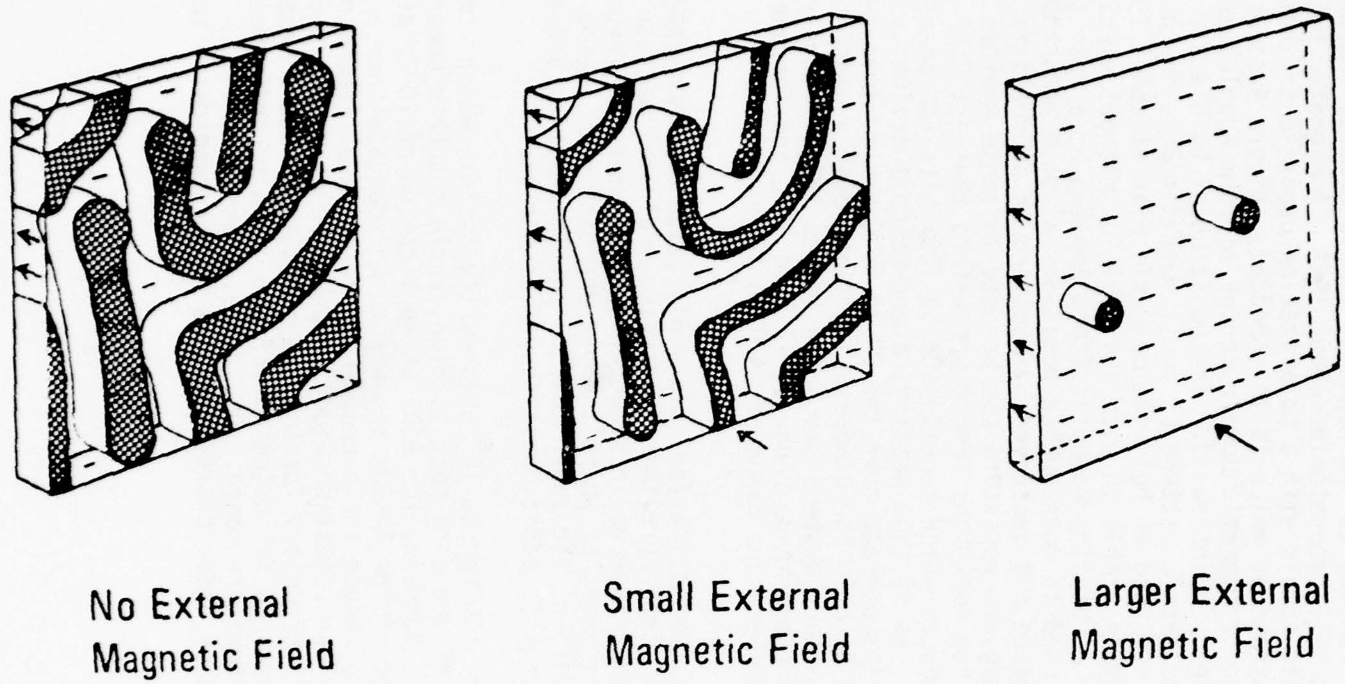

FIGURE 4. BUBBLE DOMAIN

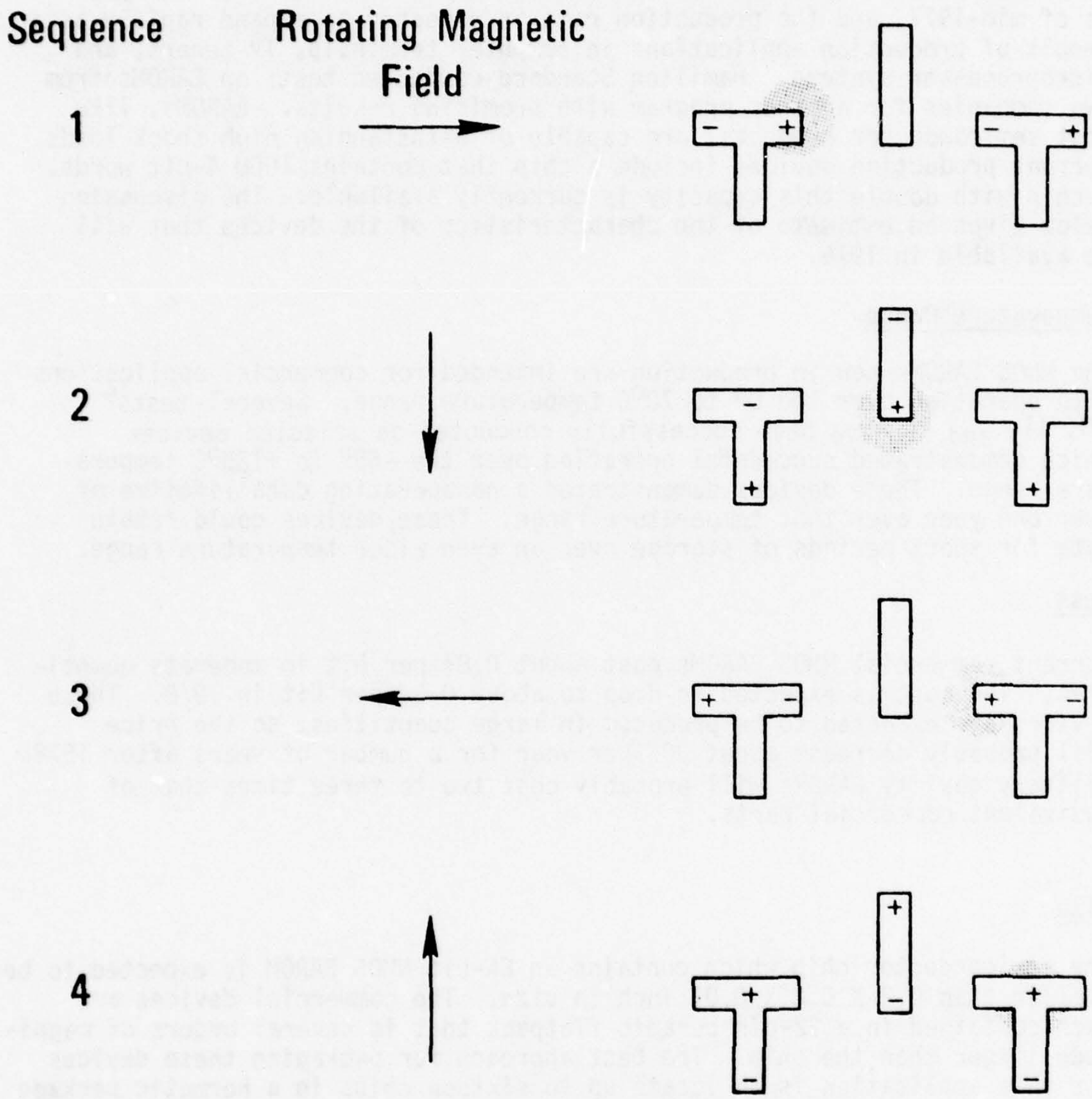

FIGURE 5. BUBBLE PROPAGATION

Metal Nitride Oxide Semiconductor (MNOS) Memories

MNOS EAROMs have been produced in moderate quantities for over two years as of mid-1977, and the production rate is expected to expand rapidly as a result of production applications in computer terminals, TV tuners, and microprocessor systems. Hamilton Standard conducted tests on EAROMs from two companies for another program with promising results. EAROMs, like most semiconductor products, are capable of withstanding high shock loads. Current production devices include a chip that contains 1000 4-bit words. A chip with double this capacity is currently available. The discussion below gives an estimate of the characteristics of the devices that will be available in 1978.

Temperature Range

The MNOS EAROMs now in production are intended for commercial applications with operation over the 0^{o} to $70^{o}C$ temperature range. Several tests[9] [10], [11], and [12] have been successfully conducted on selected devices which demonstrated successful operation over the -55^{o} to $+125^{o}C$ temperature range. These devices demonstrated a nonoperating data lifetime of over one year over that temperature range. These devices could retain data for short periods of storage over an even wider temperature range.

Cost

Current commercial MNOS EAROMs cost about 0.8¢ per bit in moderate quantities. The cost is expected to drop to about 0.5¢ per bit in 1978. These devices are expected to be produced in large quantities, so the price will probably decrease about 30% per year for a number of years after 1978. Military quality EAROMs will probably cost two to three times that of equivalent commercial parts.

Size

The semiconductor chip which contains an 8K-bit NMOS EAROM is expected to be smaller than 0.2 X 0.2 X 0.01 inch in size. The commercial devices are each contained in a 22-pin ceramic flatpack that is several orders of magnitude larger than the chip. The best approach for packaging these devices for this application is to locate up to sixteen chips in a hermetic package with a volume of 1.5 cubic inches, along with a 4-bit chip select circuit. This approach not only greatly reduces the volume but it also improves the reliability since most of the leads can be shared with all chips, thus reducing the number of leads and hermetic packages by more than an order of magnitude.

Power and Data Rate

An 8K-Bit MNOS EAROM operating at the maximum write rate of 8K bits per second is estimated to dissipate about 0.4 watt, or 50 microwatts per bit per second. The maximum erase rate in the word mode is one-tenth the maximum write rate, so the dissipation during the erase mode is 500 microwatts per bit per second, or a combined dissipation of 550 microwatts per bit per second. If all of the chips are operated in parallel, each chip in the memory will have about this dissipation, even though data is being written or erased in only one chip at a time. Thus, a 128K-bit memory will have a dissipation of 8800 microwatts per bit per second. This dissipation could be significantly reduced by increasing the circuit complexity, but this does not seem warranted because the dissipation will still be very low as a result of the low average rate. The 800 bits per second maximum erase rate for NMOS EAROM excludes voice or audio data as a parameter since a great number of chips would have to be utilized in parallel.

Life

MNOS EAROMs have a limited lifetime as a result of degradation of the nitride film during many erase and write cycles. Current devices are limited to 10^5 erase-write cycles per word. AIRS applications should average less than two erase-write cycle per word per hour, so the memory lifetime will exceed 10^5 hours.

Magnetic Bubble Memories

Magnetic bubble memories are being developed by Bell Laboratories, Rockwell, Texas Instruments, and IBM in this country and by several companies in Europe and Japan. Bell Laboratories [13, 14] have developed a 272K-bit Serial Bubble Store which may be available to government equipment suppliers in 1977. Texas Instruments[16, 17] is developing a 100K-bit bubble package and several support circuits which are scheduled to be available in 1977. They are also developing bubble memory systems for airborne and space applications to replace electromechanical recorders.

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[13] Radner, Raymond J. and Wuorinen, John H., MAGNETIC BUBBLE MEMORY STORE, 1976 IEEE International Solid-State Circuit Conference

[14] Bobeck, Andrew H., Bonyhard, Peter I. and Geusic, Joseph E., MAGNETIC BUBBLES--AN EMERGING NEW MEMORY TECHNOLOGY, Proceedings of IEEE, Vol. 63, No. 8, August 1975

[15] Lee, David M., and Naden, Rex A., BUBBLE MEMORY FOR MILITARY MASS STORAGE REQUIREMENTS, Contract No. F-33615-75-C-1228

[16] Naden, R.A., Keenan, W.R., and Lee, D.M., ELECTRICAL CHARACTERIZATION OF A PACKAGED 100-K BIT MAJOR/MINOR LOOP BUBBLE DEVICE, Contract No. F33615-75-C-1228.

TI is also developing bubble memory systems for use in their computer and terminal product lines. Rockwell is developing a lrage-capacity flight recorder for space applications. They are also developing bubble memory systems for use in computer and terminal equipment. Volume production of these devices is scheduled to begin at several U.S. companies in 1977. These devices are rugged, and should be capable of withstanding high stock loads. The performance of bubble memory devices should increase and the price decrease by 1978, as a result of production and field experience accumulated by that time. The discussion below gives an estimate of the characteristics of bubble memory devices which will be available in 1978.

Temperature Range

While prototype magnetic bubble memory systems have been designed for operation over the 0° to 50°C temperature range, it appears that the basic bubble memory packages are capable of operating over a wider temperature range. Bubble memory packages have been successfully operated[15] over the -30° to +80°C temperature range, and they have demonstrated the ability to retain data in the nonoperating state over the -50° to +100°C temperature range. These devices incorporated INDOX permanent magnets which change the bias magnetic field with temperature to compensate for changes in the garnet properties with temperature. Writing can be accomplished over a wider temperature range than reading.

Additional temperature compensation can be applied to the magnetic bias, drive current, and write current to extend the operating temperature range without making the changes to the basic bubble substrate. Some further improvement in the temperature capabilities of bubble memory substrates can be anticipated over the next five years, but the extra cost of producing special devices will probably make it undesirable to make major changes from the devices being produced in large quantities for the commercial market. Thus, bubble memory devices should be available in 1978 which can be used in the crash recorder to store data over the -30° to +80°C temperature range and to retain stored data over the -50° to +100°C temperature range. Tests would have to be conducted on several devices to determine whether it is practical to extend these temperature limits through improved designs of the magnetic package and the support circuits.

Cost

Current cost projections from several companies indicate that magnetic bubble devices will cost about 0.05¢ per bit at the bubble package level and about 0.075¢ per bit at the printed circuit card level for commercial production devices in early 1978. Military quality parts will probably cost two to three times that of commercial parts. The cost will probably drop at about one half the rate of semiconductor RAM as a result of the large electromagnetic content of the bubble memory package, so that the price of magnetic bubble devices is expected to decrease about 15% per year.

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[17] Cheu, T.T., Bohning, O.D., et al, INVESTIGATION OF SYSTEM INTEGRATION METHODS FOR BUBBLE DOMAIN FLIGHT RECORDERS, Contract No. NAS 1-12435.

Size

Prototype bubble memory packages occupy about 5 cubic inches per million bits for packages containing 100K to 270K bits. The TI package contains about 100K bits and is 1.0 X 1.1 X 0.4 inches in size, while the Bell Laboratories package contains 272K bits and is 1.2 X 2.5 X 0.6 inches in size. This density will probably double when the next generation of bubble memory devices enters production around 1980. The low signal level associated with bubble memory chips can cause noise problems when the bubble memory package is separated from the associated sense and drive electronics. Thus, it may be necessary to include some electronics with the magnetic package in the protected portions of the candidate accident recorder to avoid noise problems. This could increase the volume in the protected compartment to as much as 20 cubic inches per million bit bubble memory package.

Power

Prototype bubble memory devices containing 272K bits dissipate about 0.5 watt in the bubble memory package and 2.5 watts in the associated electronics when operating at the maximum data rate of 48 KHz. The memory can be energized only when data is to be recorded, thus making the power dissipation proportional to the association data rate, or about 10 microwatts per bit per second in the bubble package and 50 microwatts per bit per second in the associated electronics.

Life

There is no known cause which limits the useful life of bubble memory devices.

4.6 VOICE RECORDING TECHNOLOGY

Function of Voice Recorder

The function of the voice recorder aboard the aircraft is to record intercrew communications, radio communications, and cockpit audio on a crash-survivable machine. Thus, in the event of a crash or incident, the survivable recorder may be replayed, allowing the investigator to go back in time and attempt to reconstruct the event.

The crew conversation during the emergency, along with cockpit audio, is used in an attempt to establish the cause of the emergency and the procedures used by the crew in coping with the incident. The voice recorder continues to be a valuable tool in the investigation of mishaps, since it sometimes provides the only available information of the flight crew's observations and analysis of conditions aboard the vehicle. The number of audio channels provided for recording (usually between one and four) depends upon the application and vehicle. Typically, monitoring is performed on communications spoken or received on microphones, headsets or speakers, as well as a cockpit-mounted area microphone.

Present Voice Recorder Implementation

Present-Day Recorders

Voice recorders have been mandatory on certain classes of commercial aircraft since 1966. These recorders are governed by FAA requirements TSO-C84[18] and TSO-C51a, and are standardized to ARINC characteristic #557[19]. Recorders for military vehicles may or may not be combined with the Digital Data Recorder and are quite often provided in an ejectable air foil package with radio locator and floatation features. Table 19 summarizes airborne voice recorders with commercial aircraft recorders tending to be standardized against ARINC #557. Recorders used on military aircraft tend to be less standardized and more complex due to the requirement of many cases to have the recorder be ejectable. Figure 6 depicts a typical block diagram of an aircraft voice recorder and identifies the major components. Table 20 depicts a typical specification for a voice recorder.

Voice signals (normally from one to four separate channels) are received and amplified to suitable level and mixed with a high-frequency bias signal to reduce distortion. The resultant signal is then passed to the recording head for magnetizing the recording tape. Recording is normally performed on a record/erase cycle so that the latest 15 to 30 minutes of operation is retained on the recording medium. Thus, as new voice is recorded, the old voice is erased.

Figure 7 depicts how this is accomplished. The magnetic tape is transferred between reels. The action continues on an alternating basis. In practice, several tracks may actually be employed, and multiple heads must be provided for the read, write, and erase functions. Circuits are provided to drive the tape at a relatively constant speed, to reverse the tape direction and switch the the head signals as required.

Limitations in Present Voice Recorders

As can be seen from the previous paragraphs the conventional recorders, whether for voice, data, or both, are partly electronic circuits and partly mechanical hardware. While electronic circuitry reliability continues to improve and size can usually be further reduced as further circuit integration takes place, the mechanical portion of conventional tape recorders appears to be reaching a plateau with regard to size, weight, cost, and reliability. These devices can not be expected to improve significantly beyond their present level. Further drawbacks of the mechanical recorder are its requirement for periodic maintenance, such as manual checks of recording quality, and head and tape cleaning and replacement. Maintenance of the mechanical tape recorder must also be carried out under clean conditions to preclude contamination of heads and tape. The failure mode

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18 FAA TSO-C84

19 ARINC Characteristic #557. Aeronautical Radio Inc.

TABLE 19. TYPICAL PRESENT AIRBORNE VOICE RECORDING SYSTEMS

Characteristic	Weight	Size	Volume	Power	Voice Channels	Data Channels	Recording Time	Usage
ARINC 557 TSO-C84	17 to 22 lbs	1/2 ATR - SHORT	470 cu in.	15 to 20 watts	4	None	30 min.	majority commercial some military
Specialized	24 to 50 lbs	--	2000 to 5000 cu in.	20 to 30 watts	1 to 3	Yes	30 min.	military with beacon & airfoil

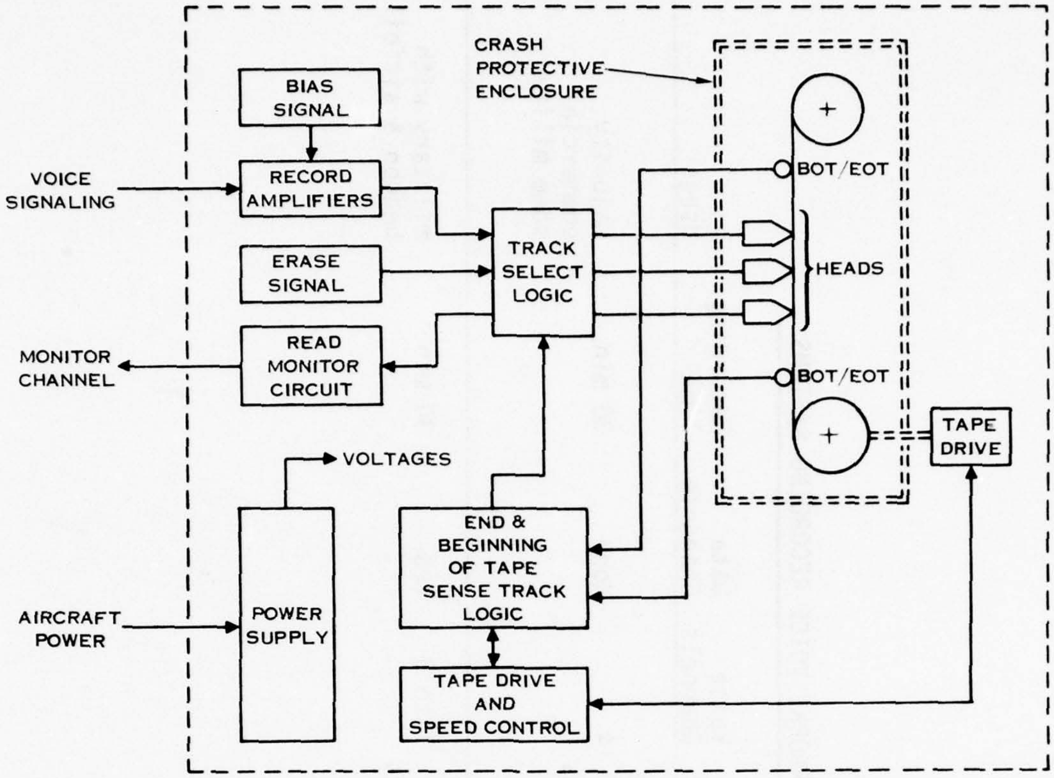

FIGURE 6. BLOCK DIAGRAM OF TYPICAL VOICE RECORDER

TABLE 20. TYPICAL VOICE RECORDER ELECTRICAL CHARACTERISTICS

1) Recording Channels - 1-4
2) Recording Time - 30 Min.
3) Audio Input - 500 mV @ 2000 Ohms
4) Frequency Response - 350 to 3000 Hz ($\pm$3db)
5) Distortion - Less than 5% @ 1000 Hz
6) WOW & Flutter - Less than 2%
7) Crosstalk - (between channels) - at least 35db
8) Recorded Signal to noise ratio - 40db min.
9) Tape Speed - 2 inches per second
10) Audio Output - 350 to 3000 Hz;
Headphones 600 Ohm, 10 mV

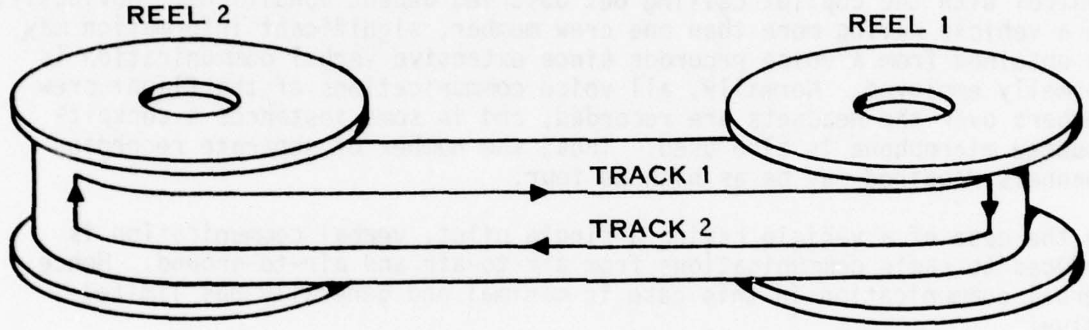

FIGURE 7. TYPICAL METHOD OF RECORDING

of mechanical recorders tends to be total and not graceful; happening often without any warning. Recording the voice signals using techniques other than by a magnetic tape recorder now appears to be feasible in the near term. A recording technique utilizing a solid-state memory would eliminate many of the limitations detailed above since mechanical moving parts would not be employed.

Requirements for AIRS

The voice recording requirements can vary depending upon the application, the vehicle being considered, and the number of crew members. For example, in a vehicle with more than one pilot, the checklists may be orally called out. As another example, on a landing approach, the pilot may be in control with the copilot calling out observed decent conditions. Obviously, in a vehicle having more than one crew member, significant information may be obtained from a voice recorder since extensive verbal communication is normally employed. Normally, all voice communications of the flight crew members over the headsets are recorded, and in some instances a cockpit-mounted microphone is also used. Thus, the number of separate recording channels required may be as high as four.

In the case of a vehicle having a single pilot, verbal communication is reduced to radio communications from air-to-air and air-to-ground. Hence, verbal communication in this case is minimal and generally has limited value.

In vehicles with high cockpit noise levels, such as helicopters, an area microphone for recording crew communications is of little benefit other than to possibly correlate other audible sounds such as engine noise or aural warnings. Newer generation helicopters do have a lower ambient cockpit noise level, and in these specific installations the use of an area microphone may have some merit.

Considering the above factors, it appears that a single-channel voice recorder connected to the interphone system may be sufficient. This one channel would monitor the crew intercommunication and would also monitor radio communications. This recording would then encompass a major portion of the information available. A recording duration of 30 minutes is typical for present electromechanical voice recorders. However, if solid-state techniques are to be pursued, the length of recording should be reconsidered. In a solid-state recorder different techniques must be used to process and store the information. To store the equivalent of 30 minutes of voice would require an exceptionally large memory, especially if more than one channel were required. A study of solid-state audio storage has shown that 2 to 5 minutes may be practical, considering the cost of the memory system. Further detail is given in the following section.

Solid-State Voice Recorder System Design

Implementation

Present-day voice recorders accept the audio inputs and, after pre-conditioning the signal, it is directly recorded on magnetic tape as an analog signal. To record the same audio signal with a solid-state recorder requires a different approach and implementation:

1. The analog audio signal must be converted into digital form since solid-state memories are inherently digital.

2. Since solid-state memories have no moving magnetic tape, recording (or more correctly storage) is only required to take place when speech audio is present. This assumes that the value of cockpit area audio is marginal, and therefore only speech is to be stored. Mechanical recorders must be kept running since the start and stop time is fairly long and would cause some speech to be lost. More importantly the time correlation would be lost when the recording was replayed.

3. Since the voice signal is to be digitized, the encoding form, the memory size, and the recording duration become the important parameters in the type of memory selection.

To amplify on the memory selection factor, an appreciation of the charateristics of the voice input is necessary. The voice signal has a fairly wide frequency spectrum, yet it can be limited to frequencies lower than 4 KHz without loss of intelligibility. Audio signals in this range can then be digitized via various techniques, yielding acceptable quality and coherence.

The most straightforward technique for digitizing the analog signal with a highest frequency component N is to sample it at least at or higher than the Nyquist rate of 2N. The above audio signal can then be fed to an Analog-to-Digital converter operating at a sampling rate of 8 KHz and each sample would be coded with 12 bits (4096 steps), which is sufficient to provide good quality. This would give a bit rate of (8X12) 96K bits/sec.

At this data rate, a memory of 1 million bits capacity would be full in 10.4 seconds, which would be rather a short time for voice recording application. Hence, other techniques must be investigated to reduce the average data rate; that is, reduce the number of digital bits required to describe a given voice signal so that a longer recording period and a more manageable memory size can be accommodated. It can be seen that even with an order of magnitude improvement in average data rate reduction, the memory capacity required is such that a high bit density per chip (probably greater than 100K bits/chip and low cost/bit must be obtained (Reference Section 4.5).

The memory technology study shows that the only practical candidate for this application is the magnetic bubble memory system.

Digital Encoding of Voice Signals

Various techniques may be used to reduce the amount of digital data required to be stored for voice inputs. The techniques roughly fall into two categories: vocoders and encoders.

Vocoders

Vocoders operate on the principle of speech analysis. Typically for a digital vocoder the input analog speech signal would first be conditioned to normalize the speech power spectrum. The signal would then be put through a real-time spectrum analyzer, and the resulting signal spectrum would be digitally encoded. Separate detection means would be used to determine the basic pitch frequency, and voice and unvoiced periods. This information could then be digitally combined, together with synchronization data, to provide a data rate in the region of 2000 to 3000 bits/sec. To reconstruct the speech signal requires a complement of the above functions to synthesize the speech back from the digital signal.

It can be seen that the data rate is greatly reduced from the previously indicated 96K bits/sec, allcwing a longer recording period to be obtained for a practical memory/size. However, this is at the expense of circuit complexity. Preliminary investigations indicate that using a vocoder reduces or makes practical a solid-state memory, but it also increases the hardware to the point that the system would not meet the size and cost goals of this application in the near future. With the advent of very-high-speed microprocessors and the large gains being made in LSI technology, this approach may become viable in the 1980's.

Encoding

Encoding refers to a technique of sampling the input speech waveform at some sampling rate and then digitizing the resulting samples. The system outlined earlier was an implementation of a linear PCM encoder[20, 21] where the speech waveform was first filtered to reduce the frequency band to less than 4KHz and then sampled at 8KHz. The samples were then digitized with 12 bits. Figure 8 is an example of digital encoding. The signal (a) is sampled at a high rate approximately 12 times the signal frequency (in this example). Each of the samples is then digitized with a 3-bit converter, shown in (d), and the corresponding digital output signal (f) can then be stored and at a later time used to reconstruct the original signal (g).

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20 Jayant, N.S., DIGITAL CODING OF SPEECH WAVEFORMS, PCM, DPCM, AND DM QUANTIZERS, Proceedings of IEEE, May 1974.

21 Noll, D, A COMPARATIVE STUDY OF VARIOUS QUANTIZATION SCHEMES FOR SPEECH ENCODING, BSTJ No. 75.

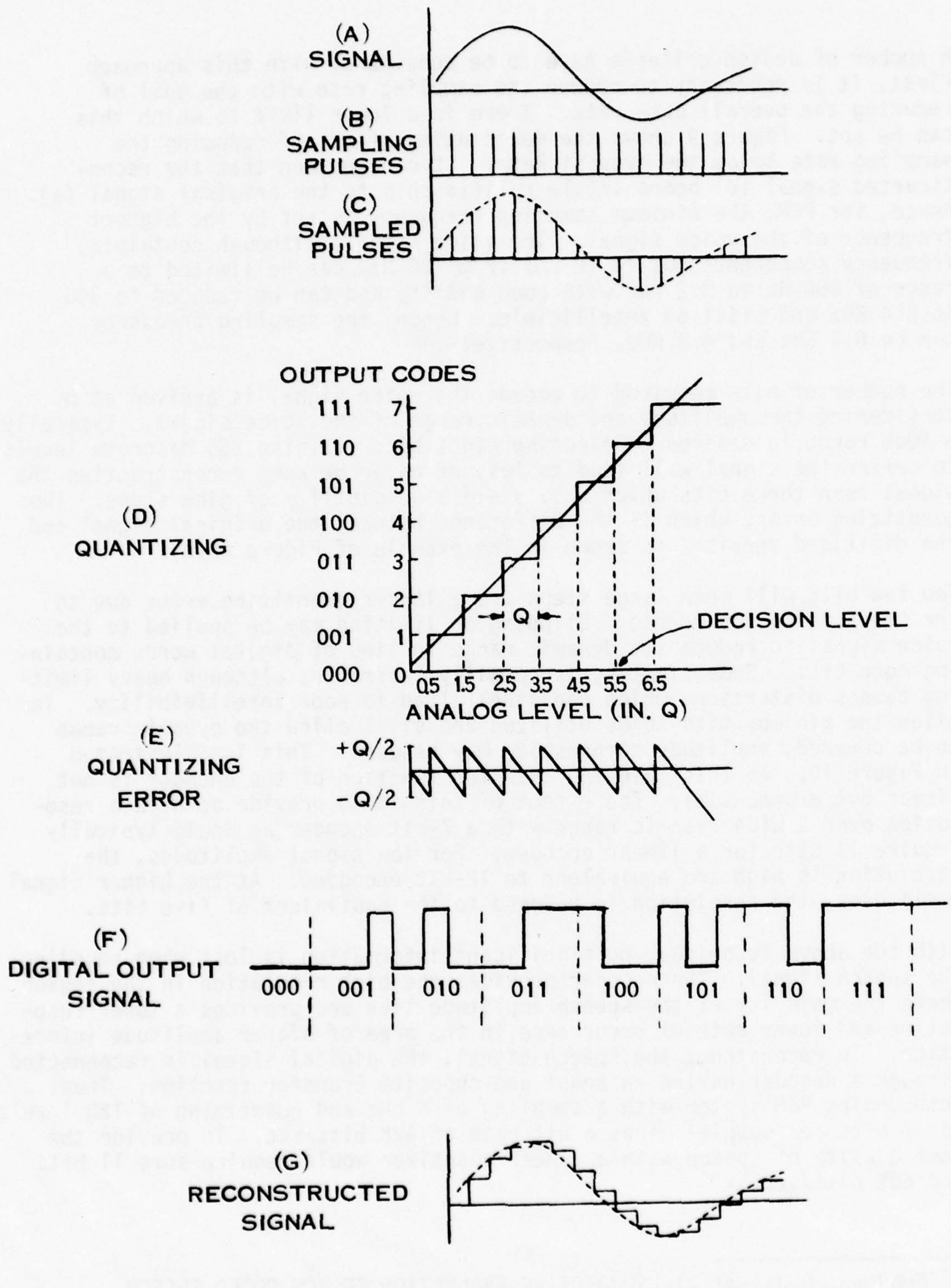

FIGURE 8. DIGITAL ENCODING USING LINEAR PCM

A number of design criteria have to be considered with this approach. First, it is necessary to reduce the sampling rate with the goal of reducing the overall data rate. There is a lower limit to which this can be set. Figure 9 shows the devastating effect of reducing the sampling rate below the Nyquist Rate. It can be seen that the reconstructed signal (c) bears little relationship to the original signal (a). Hence, for PCM, the minimum sampling frequency is set by the highest frequency of the voice signal. The voice signal, although containing frequency components out to 10 KHz from 100 Hz, can be limited to a range of 300 Hz to 3.2 KHz with good quality and can be reduced to 300 to 2.4 KHz and still be intelligible. Hence, the sampling frequency can be 6.4 KHz and 4.8 KHz, respectively.[22]

The number of bits required to encode the voice signal is arrived at by considering the amplitude and dynamic range of the voice signal. Typically, a 40db range is desired. Selecting eight bits yielding 256 discrete levels to define the signal will lead to less of an error when reconstructing the signal than three bits which only yield a possibility of nine steps. The quantizing error, which is the difference between the original signal and the digitized version, is shown in the example of Figure 8 (e).

Too few bits will mean large steps and a larger quantizing error due to the steps being too coarse. Clipping or limiting may be applied to the voice signal to reduce its dynamic range in lieu of digital words containing more bits. Some limiting is normally desirable, although heavy limiting causes distortion, which can itself lead to poor intelligibility. To allow the minimum bits to be utilized and still allow the dynamic range to be covered, amplitude compression may be used. This is illustrated in Figure 10. In this case the transfer function of the encoder is not linear but exponential. The effect of this is to provide as high a resolution over a wide dyanmic range with a 7-bit encoder as would typically require 11 bits for a linear encoder. For low signal amplitudes, the resolution is high and equivalent to 12-bit encoding. At the higher signal amplitudes, the resolution is reduced to the equivalent of five bits.

With the above technique, no significant information is lost when encoding the speech signal. The encoder provides the high resolution in the region where the majority of the speech amplitude lies and provides a lower resolution and lower rate of occurrence in the area of higher amplitude information. To reconstruct the speech signal, the digital signal is reconnected through a decoder having an equal and opposite transfer function. Thus, a compounding PCM system with a sampling of 6 KHz and quantizing of 128 levels (or 7 bits per sample) gives a bit rate of 42K bits/sec. To provide the same quality of speech with a linear quantizer would require some 11 bits and 66K bits/sec.

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[22] Goodman, D.J., et al, SUBJECTIVE EVALUATION OF PCM CODED SPEECH, BSTJ Octo., 76.

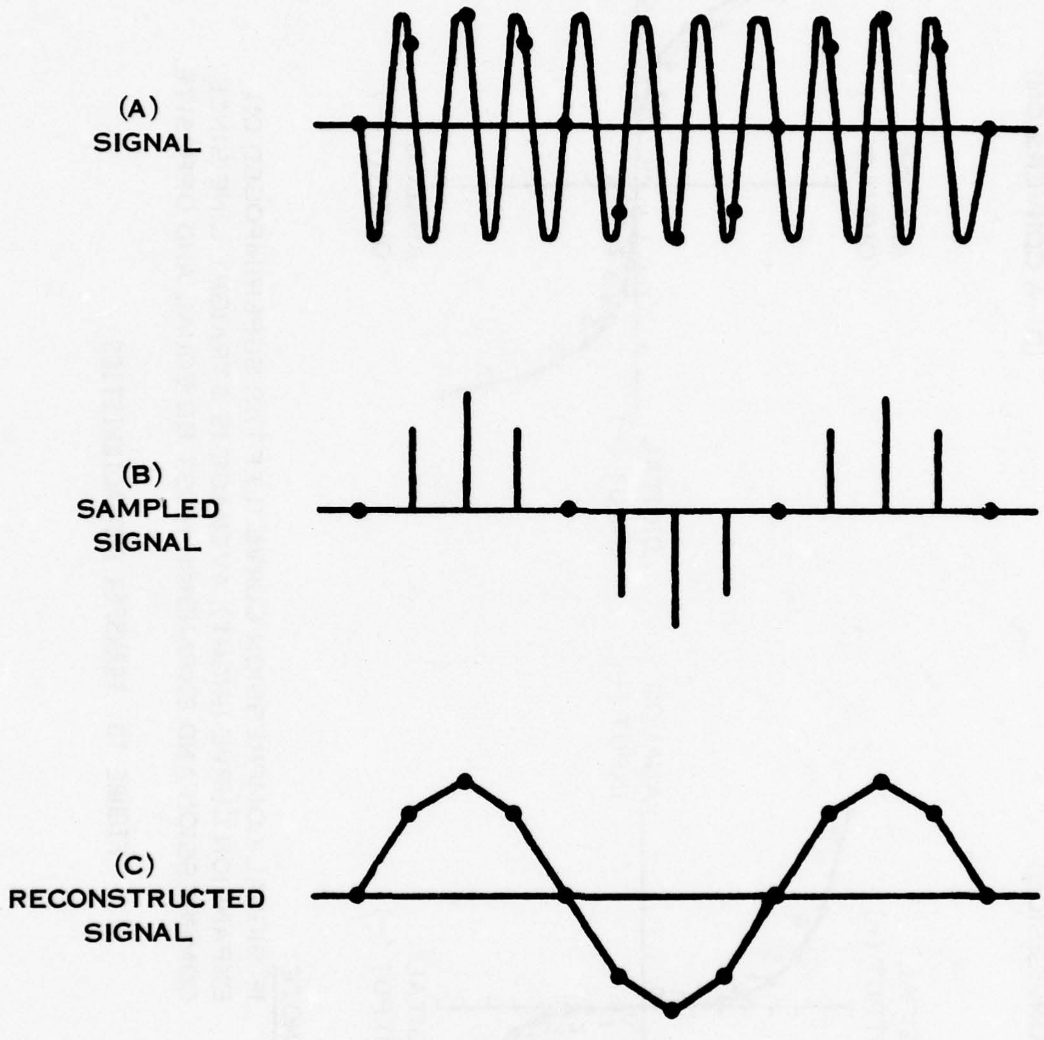
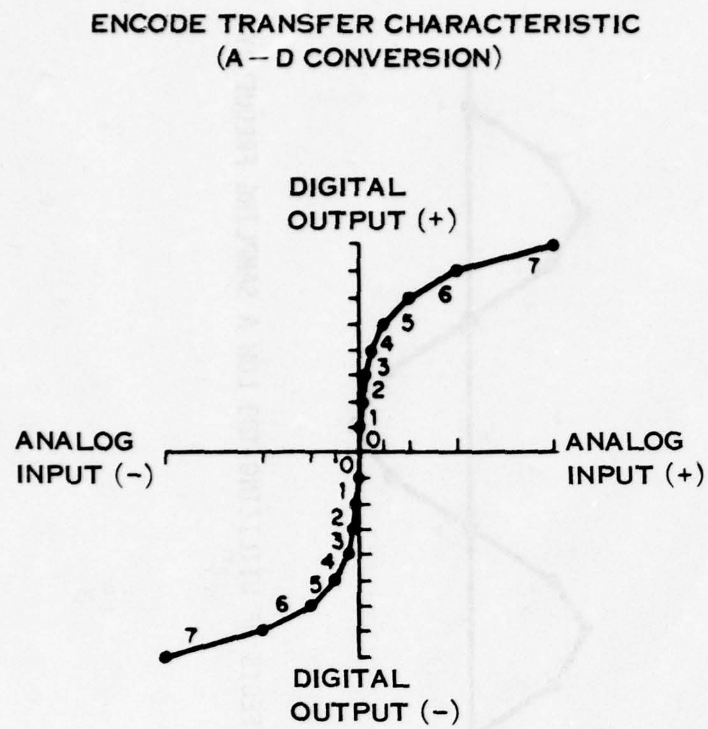
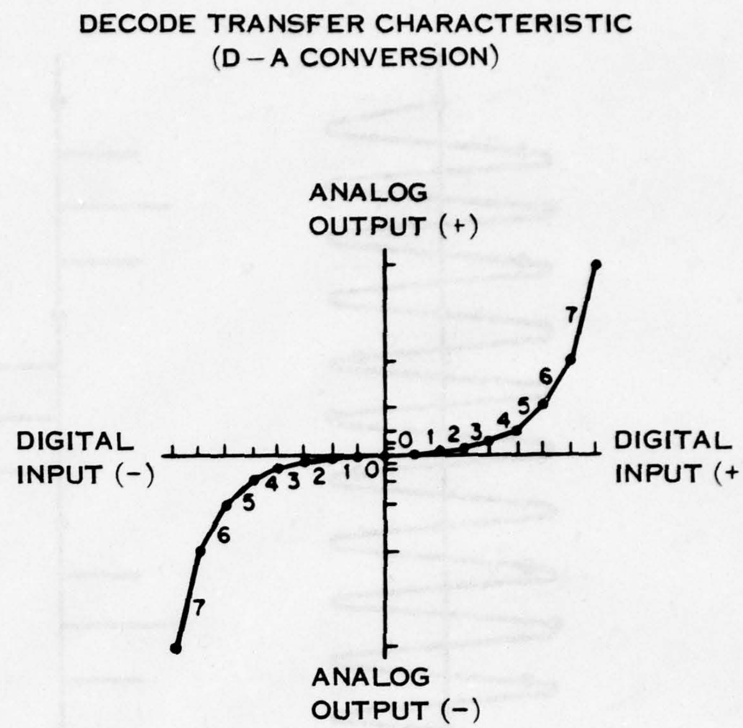


FIGURE 9. ILLUSTRATING EFFECTS OF UTILIZING TOO LOW A SAMPLING FREQUENCY





NOTE:

IF SIGNAL COMPRESSION CURVE (LEFT) IS SUPERIMPOSED ON EXPANSION CURVE (RIGHT), AVERAGE IS STRAIGHT LINE SINCE COMPRESSION AND EXPANSION MUST BE EQUAL AND OPPOSITE.

FIGURE 10. TRANSFER CHARACTERISTICS

Inspection of the speech signal shows a significant correlation between successive coded samples with a variance of the difference between samples being smaller than the variance of the speech signal itself. This fact can be utilized to differentially encode the speech signal. Thus, only the difference between successive samples is coded. Since the difference value is much smaller than the absolute value, fewer bits are required to describe it with equivalent quantizing error. Further improvement is made if the quantizing is made adaptive. The step size may be modified for each new input by a factor dependent on the knowledge of the previous samples. With this system 3 to 4 bits can suffice. At a sampling rate of 6 KHz this gives a bit rate of 18K bits/sec.

The principle of only coding the signal differences can be taken a step further with the application of delta modulation of a 1-bit (2-level) quantizer.[23] This technique has the benefit of requiring simpler circuitry to implement the encoder. However, to ensure sufficient speech quality preservation with only a 1-bit quantizer, the sampling rate must be increased higher than the Nyquist Rate to compensate for dynamic error. Figure 11 depicts a delta modulator in its simplest form. The voice signal is compared with a feedback error signal if the voice signal is larger than the error signal, then the comparator output is positive. If smaller, then the comparator output is negative. A pulse selector allows the sampling pulse through if the comparator output is positive, and disallows it if it is negative. Figure 12 shows the typical waveforms obtained. The digital output pulses are also fed back to an integrating circuit (a simple resistor-capacitor) so that the digital signals can be reconstructed into an analog signal to form the feedback input to the comparator. This form of modulator may have to be operated as high as 80-90 KHz to provide the necessary quality. Since only one bit is required, the sampling rate is the same as the data rate. Obviously at these bit rates, no advantages are obtained over PCM; however, these rates may be reduced. Figure 13 shows the errors obtained using a delta modulator of the linear type. In this case the coder operates on the basis of approximating an input time function by a series of linear segments. Slope overload occurs when the step size delta is too small to follow a steep segment of the input waveform. Granularity refers to a situation where the staircase function hunts around a relatively flat section of the input function with a step size too large relative to the local slope characteristic of the input. Therefore, relatively small values of "Delta" accentuate slope overload, while relatively large values of "Delta" increase granularity under low rate conditions. These errors can be reduced by adapting the step size to the rate of change of the input signal, and this is illustrated in Figure 14. The variable step size "Delta" increases during a steep segment of the input and decreases when the delta encoder is quantizing a slowly varying section of the input signal.[24]

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23 Schindler, H.R., DELTA MODULATION, IEEE Spectrum 1970.

24 Cummiskey, P., Tayant, N.S., ADAPTIVE QUANTIZATION IN DIFFERENTIAL PCM CODING OF SPEECH, BSTJ Sept., 73.

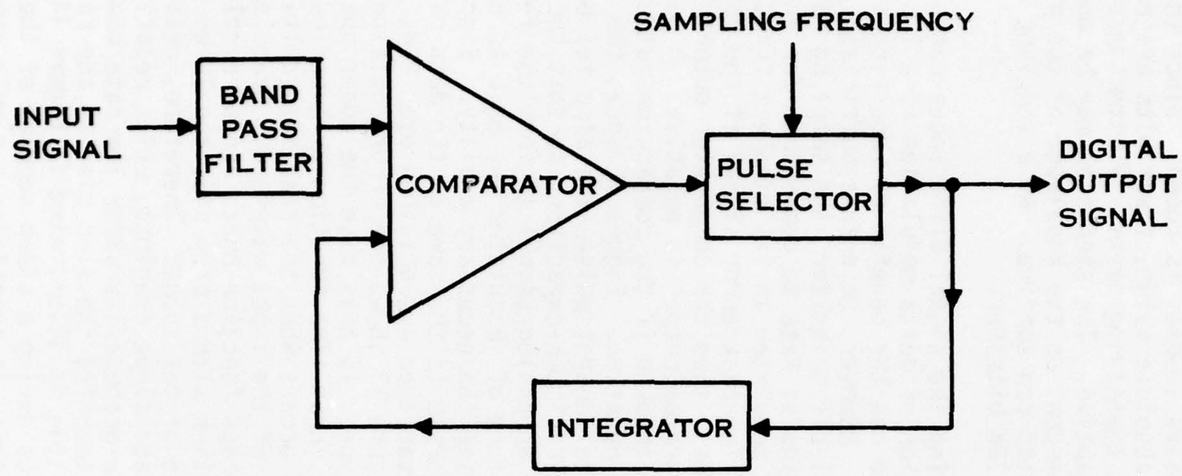

FIGURE 11. BASIC DELTA MODULATOR

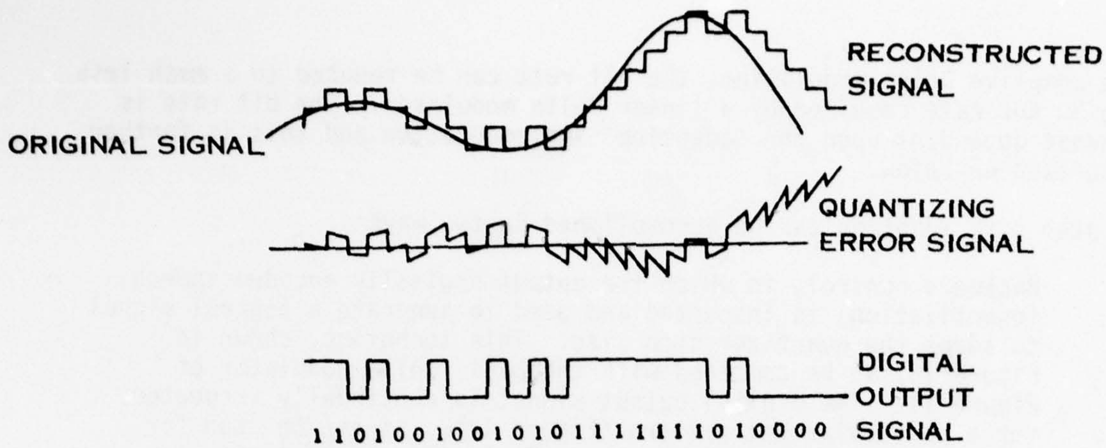

FIGURE 12. DELTA MODULATOR WAVEFORMS

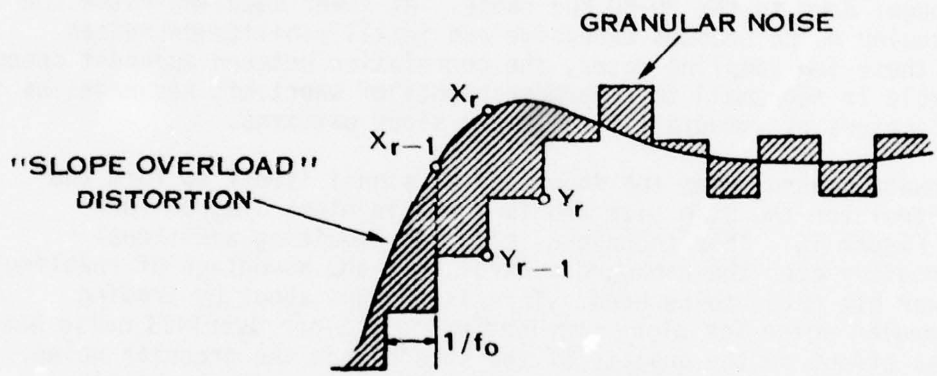

FIGURE 13. LINEAR DELTA MODULATION

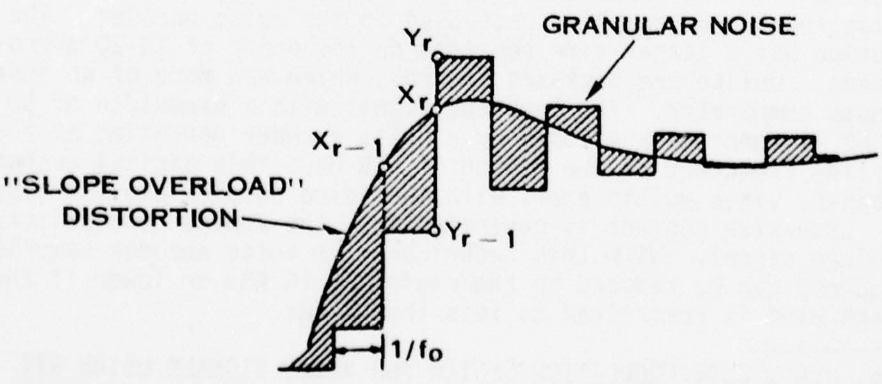

FIGURE 14. ADAPTIVE DELTA MODULATION

With adaptive Delta modulation, the bit rate can be reduced to a much less than 50 KHz rate required by a linear Delta modulator. The bit rate is somewhat dependent upon the 'adaption' implementation and this is further elaborated on below.

The step size adaption can be accomplished in two ways:

(1) Backward control, in which the output digitally encoded speech (quantization) is inspected and used to generate a control signal to adapt the quantizer step size. This technique, shown in Figure 15,can be compared with the basic delta modulator of Figure 11. The digital output signal is continually inspected for a particular bit pattern (Figure 12). It can be seen for slope increases that the pattern of all '1's predominate, for slop decreases all '0's dominate, and for constant signal levels, alternating '1' and '0' dominate. Hence, by recognizing these bit patterns the step size magnitude can be varied or changed in polarity accordingly. Sampling rates with such an encoder can be brought down to the 20-30 KHz range. At lower sampling rates the granular noise becomes excessive and intelligibility decreases. At these low sampling rates, the correlation between adjacent speech sample is too small to regard snapshots of short bit sequences as indicators of immediately following slope patterns.

(2) Forward control uses the input analog signal itself to form the control for the step size and is shown in block diagram form in Figure 16. This technique, although requiring additional circuitry over the backward control, has the advantage of enabling lower bit rates to be used. This is brought about by trading granular noise for slope overload noise. Slope overload noise has less effect on the quality of the speech than the granular noise. From the diagram it can be seen that the voice signal encoding loop is typical of an adaptive Delta encoder; however, the step size is varied by an envelope detector. The envelope signal is detected from the input analog signal itself and, hence, is not influenced by the sampling rate used in the voice encoder. The adaption has a longer time constant on the order of 10-20 micro-seconds. Unlike the backward control, which was more of an instantaneous comparator. The envelope signal with a bandwidth of 50 to 100 Hz is separately encoded by a Delta encoder operating at a low sampling frequency in the region of 500 Hz. This digital output is combined, via a multiplexer, with the voice encoded digital signal. The step-size control is generated from the analog reconstituted envelope signal. With this technique, the voice encoder sampling frequency can be reduced to the region of 10 KHz or lower if the speech band is restricted to less than 3 KHz.

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25 Greefkes, J.A., CODE MODULATION SYSTEM FOR VOICE SIGNALS USING BIT RATES LESS THAN 8 KBPS, Proceedings of IEEE Int Conf Communications (Seattle, Washington, June, 1973).

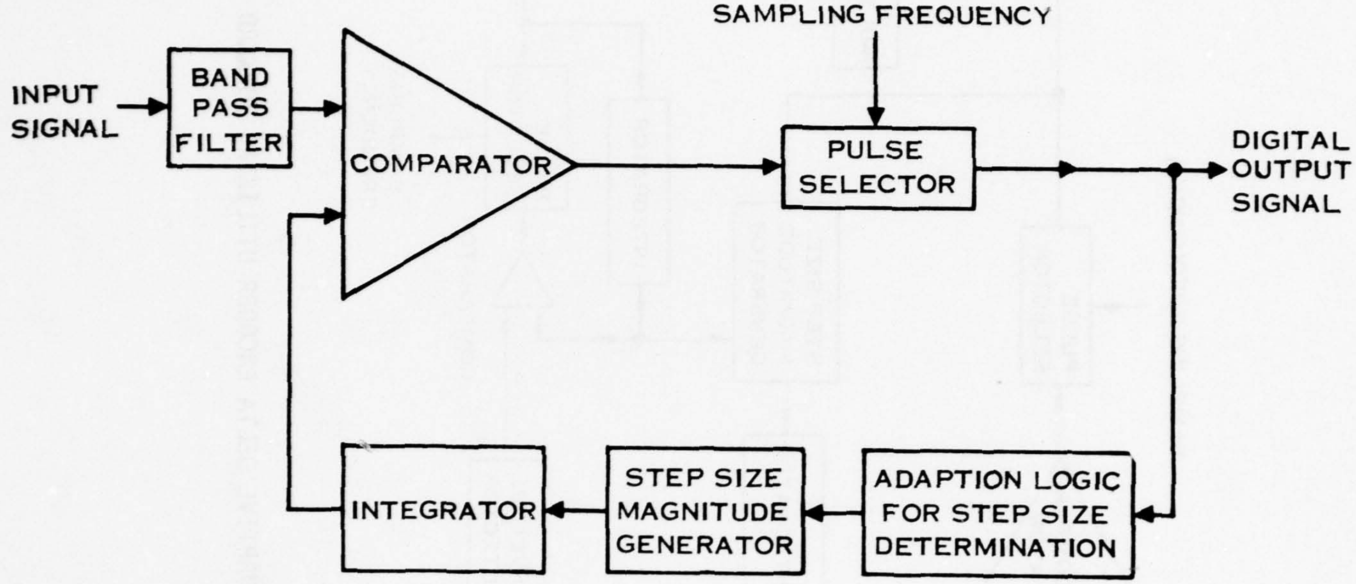

FIGURE 15. ADAPTIVE DELTA ENCODER UTILIZING BACKWARD CONTROL

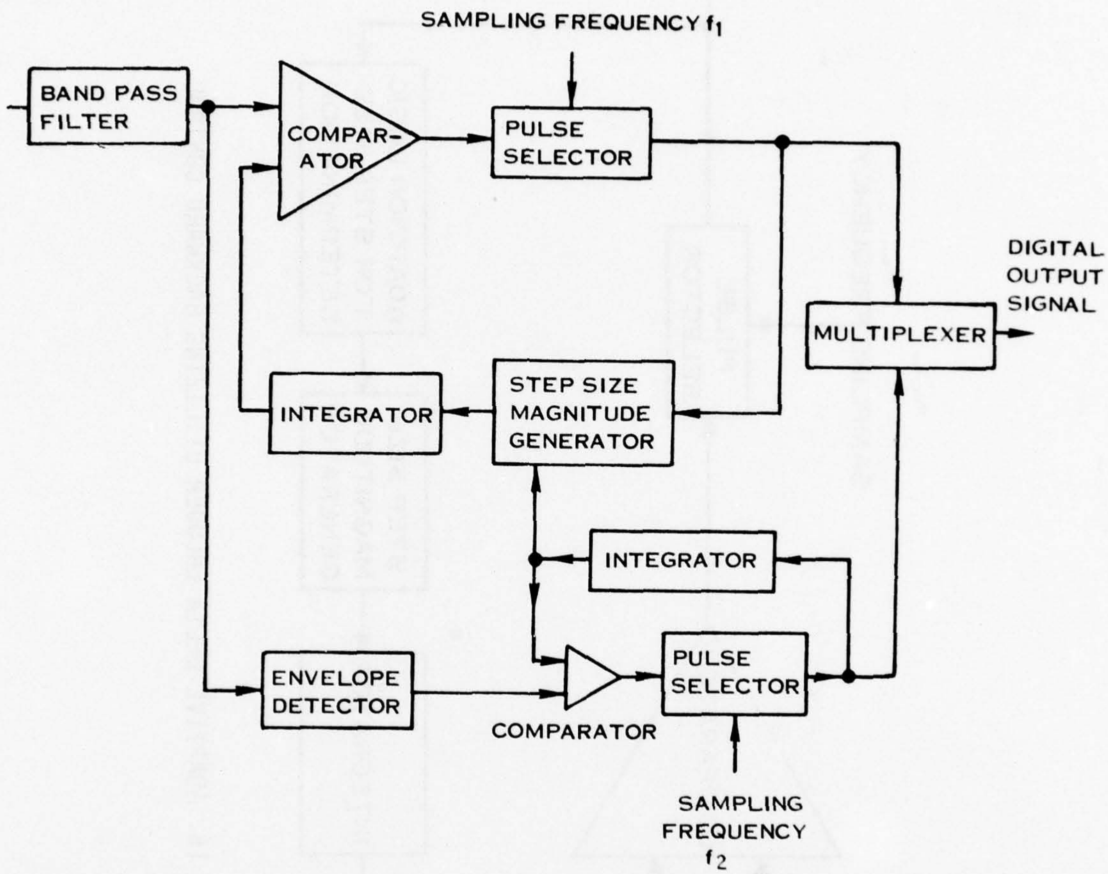

FIGURE 16. ADAPTIVE DELTA ENCODER UTILIZING FORWARD CONTROL

From the preceding section it can be seen that the number of bits required to represent a voice signal lies in the range of 3K to 10K bits per second of speech. The lower the number of bits required, the smaller the memory size will be, or the longer the recording period will be, for a given memory size. Techniques to obtain lower bit rates than 7-10 KHz involve increasingly complex circuits. The extreme lower limit is around 2 to 3 KHz, utilizing the previously described vocoders. With the present state of the art, it appears that greater strides are or will be made in memories in the areas of number of bits/chip and cost/bit, than in reducing cost and complexity of the functions required for such items as vocoders. Based on the above analysis, the AIRS solid-state voice recorder function having the greatest potential is a forward adaptive Delta encoder with a data rate in the region of 7 to 10 KHz with a memory size as defined below and a memory of the serial magnetic bubble type as discussed in Section 4.5. These devices are now being produced at 272K bits/chip, which makes practical memory sizes in the region of a million bits. Figure 17 shows the relationship between data rate, memory size, and recording time. It can be seen that for a data rate in the region of 7-10 KHz a one-megabit memory could provide 120 seconds of one channel of continuous audio storage. Since normal speed is intermittent, 2 minutes of continuous storage appears to allow a minimum acceptable storage capability. As mentioned earlier, unlike a magnetic recorder, a solid-state recorder can be stopped and started as required so that data storage only need take place during voice periods. Synchronization and timing codes can be attached to each package of coded voice data and the packages packed together. For reproduction of the signals, the packages can be put back together with the right pauses and time correlation as the original signal. It is estimated that the original 120 seconds of storage, depending upon the voiced to unvoiced periods, could extend to cover a period of two to four times the number of seconds of real time. Hence, a recording time of 4 to 8 minutes is possible for a single-voice channel, which may be sufficient in the majority of helicopter applications to at least cover the critical incident period. An examination of the system and memory requirement of data recording versus voice audio recording using solid-state techniques indicates little commonality. Audio recording requires an order of magnitude more memory space to cover the same approximate real-time period. Also, the signal conditioning, digitization, and compression techniques in hardware and software are completely different. It is therefore likely that audio recording will appear as a separate electrical function from data recording in future systems, except for possibly sharing a common power supply, time base, and chassis. If a combined voice/data solid-state system is produced, the cost of the system appears relatively high, i.e., increases a system cost by a large measure (almost 2 to 1). However, the emerging memory technology and refinements in audio digitization, and compression show promise in the future for more voice storage capability per dollar spent.

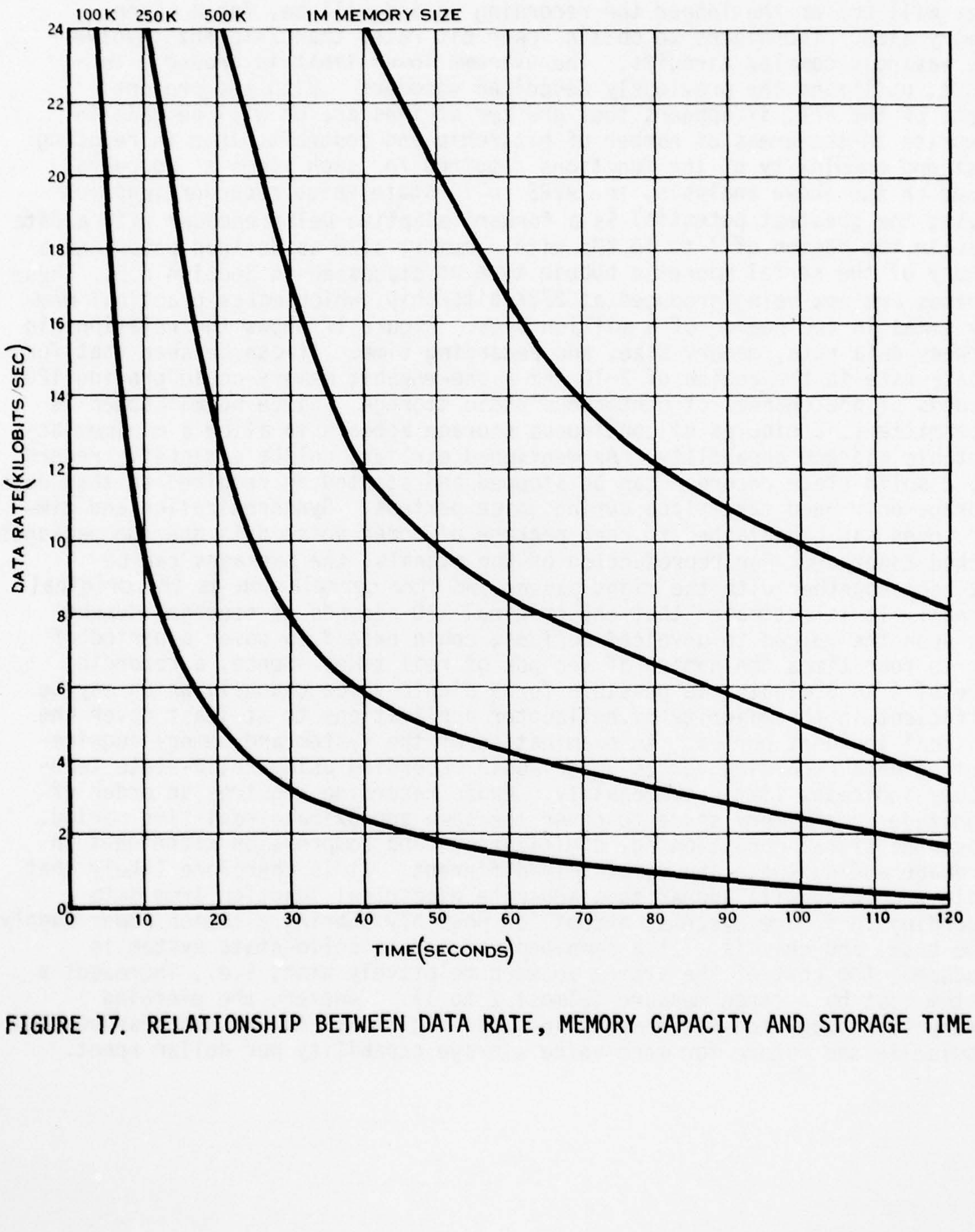

FIGURE 17. RELATIONSHIP BETWEEN DATA RATE, MEMORY CAPACITY AND STORAGE TIME

4.7 DATA ORGANIZATION AND PROCESSING

The organization and processing of the digital data is one of the more important aspects of this study. In order to minimize the amount of memory needed such that solid-state data storage techniques can be considered or, conversely, to maximize the amount of real information that can be retained in a given memory size, it is necessary to devise the most efficient possible techniques for formatting and compressing data. Audio data manipulation was discussed in the previous section. This section deals with data from other AIRS candidate parameters. The areas that must be considered are the word size, the organization of the data frames, and the techniques that can be used to compress information by eliminating unnecessary data. The results of the analysis will give memory required as a function of flight time.

Word Size

The input signals are converted through pulse code modulation (PCM) at the required sampling rate to a digital form by the data acquisition section. In order to choose the optimum digital word size, it is essential to determine the number of bits necessary to give the required accuracy or resolution for each parameter. It is necessary to determine the maximum allowable value for the least significant bit and the total number of bits required to cover the dynamic range. It may not be necessary in all cases to uniquely define the entire range as long as the required data can be determined unambiguously without a great deal of difficulty in the post-flight analysis.

The following paragraphs give a brief analysis of the requirements for each parameter.

Time

The independent variable for the recorded data is time. It is not necessary to have an absolute time base. Absolute time would add unnecessary expense and operating inconvenience to the system. In virtually every case it will be possible to determine the correlation with absolute time by flight records or the known time of external events. However, it is necessary to know the relative time of the recorded data. This relative time is generated by the operation of the system itself. If data were recorded continuously, the relative time could be determined implicitly by the known recording rate. However, in general, the data will not be recorded continuously and it will be necessary to have a word which uniquely defines the time that each parameter is recorded. The minimum resolution required is one second, except for acceleration during impact for which a 0.25-second resolution is required. The maximum range is dependent on the organization of the data. However, it is likely that the maximum interval between a reference recording is one minute. Eight bits would then be necessary for time resolution between reference recordings for impact acceleration and six bits for all other parameters. If the reference frames are recorded once per minute, eight bits will give a total time of 256 minutes or over four hours, which is more than adequate to provide unique time reference for all data.

Airspeed

The accuracy required for airspeed is 5 knots, and the required range is 200 knots. A minimum of 6 bits would be required to give the required range with a resolution of 3.2 knots.

Heading

The required range for heading is 360 degrees. Eight bits will give a 1.4 degree resolution. If a higher degree of resolution is required, nine bits would be required, giving a resolution of 0.7 degree.

Altitude

The required range for altitude is -1000 to 20,000 feet, and the resolution should be at least 20 feet, with a small resolution desired. The organization of the altitude word is influenced by the choice of sensors and the accuracy of the analog-to-digital converter. The assumed method of determining altitude for a majority of the helicopters is the transponder code for the full range and either an existing or a new pressure sensor for improved resolution. This additional sensor allows interpolation between the 100-foot code steps. Nine bits of the digital code covers the range up to 31,000 feet, which includes the assumed helicopter operating range of 20,000 feet. The least significant bit of this code is 100 feet. The A/D converter is eight bits. With a least significant bit value of 20 feet, an eight-bit word would cover a range of approximately 5000 feet.

Acceleration

If both flight and impact accelerations are to be measured, it appears that the most economical approach is using two different sensors and ranges. When the acceleration is above the range of the lower accelerometer, the system automatically switches to the high range sensor. For the flight range, seven bits will cover the $\pm$ 5 g's with a resolution of 0.08 g, which is adequate. In the impact range, seven bits will cover the range of $\pm$ 150 g's with a resolution of 2.4 g's, which should be sufficient. One bit is required to identify which range has been selected. If impact-only accelerations are to be measured, then the full eight bits can be used for the $\pm$ 150 g range, yielding a resolution of 1.2 g's.

Pitch Attitude

The desired range for pitch is $\pm$ 90 degrees. Eight bits will give a resolution of 0.7 degree, which will meet the desired accuracy of 1 degree.

Roll Attitude

The desired range is ± 180 degrees. Nine bits are required to give a resolution of 0.7 degree.

Engine Torque

The desired range is 150%, with an accuracy of 2%. Seven bits give a resolution of 1.2%.

Rotor RPM

The desired range is also 150%, with the same desired accuracy of 2%. Again, seven bits give a resolution of 1.2%.

Engine RPM

The desired range is 120%, with an accuracy of 2%. Seven bits give a resolution of 0.8%.

Engine Exhaust Gas Temperature

With a range of up to 1700°F for some helicopters, an eight-bit word will give a 6.6°F resolution, which should be adequate.

Control Positions

Control positions can be represented by a range of 0 to 100%, with a desired accuracy of 2%. Seven bits will give a resolution of 0.7%.

Radar Altitude

The range of the radar altitude is 2000 feet. Eight bits give a resolution of 7.8 feet.

A summary of the minimum bit requirements is given in Table 21. The data processing task, both in the airborne equipment and in the ground data recovery system, can be greatly simplified by the selection of a standard word length. Standard word lengths for digital equipment are 4, 5, 8, 12 16, and 32, with 8 and 16 being the most common. It can be seen that eight bits is sufficient for all but two parameters: altitude and roll. This problem can be solved in two ways: The most significant bit can be considered a discrete bit and packed with other discretes, or the most significant bit can be implied from the context. The processing task will be simplified if the altitude code is recorded directly. The altitude code is a gray code and, by its nature, all bits must be recorded to avoid ambiguity. The most significant bit is thus recorded as one of the discrete bits. For the roll problem, bank angles at greater than 90 degrees are rare. The over 90 degrees condition could be indicated by a discrete bit. However, to save room for expansion, the over 90 degrees condition is implied from the context. A helicopter is not flown continuously upside down, thus continuous data is near zero bank. Since bank angle is tracked

TABLE 21. SUMMARY OF WORD LENGTH ANALYSIS

	MIN REQUIRED BITS	MAX RANGE	RESOLUTION
Time			
Relative (Impact) (Sec)	8	64	0.25 sec
Relative (Nonimpact) (Sec)	6	64	1 sec
TOTAL (Min)	8	4.27 hrs	1 min
Airspeed	6	200 kn	3.1 kn
Heading	8	360 deg	1.4 deg
Altitude			
Code	9	31,000 ft	100 ft
Transducer	8	5,100 ft	20 ft
Acceleration			
Flight	7	± 5g	0.08 g
Impact	7	± 150g	2.4g
Pitch	8	± 90 deg	0.7 deg
Roll	9	± 180 deg	0.7 deg
Engine Torque	7	150 pct	0.8 pct
Rotor RPM	7	150 pct	0.8 pct
Engine RPM	7	120 pct	0.8 pct
EGT	8	1700°F	6.6°F
Control Position	7	100 pct	0.7 pct
Radio Altitude	8	2,000 ft	7.8 ft

continuously, any excursion beyond 90 degrees can be uniquely determined. It is possible to pack discrete bits in with words that do not require the full eight bits. However, this practice complicates the data reduction and is not recommended unless it is a marginal situation where the addition of one more bit would cause a significant change in the data requirements such as adding another whole word and wasting the other seven bits.

Data Compression Techniques

The object of data compression is to optimize the amount of information contained in a fixed number of memory bits to take advantage of solid-state memory technology and its attendant benefits. The advantage of data compression can be seen by viewing the investigation problem backward in time from the accident or incident. In the last few seconds it is likely that many of the parameters are changing rapidly, and essentially a continuous recording of data is desired. This data will usually give a detailed account of what happened in the accident itself. However, this data might not give the basic root cause of the accident or the conditions that led to the accident. If the system records data at a continuous rate, it will not be possible to record very far back in time in consideration of limited-cost systems. In the flight up to the accident, it is likely that many parameters will change only slowly or remain essentially constant. Thus, if the recording is constant, much of the data is repetitive and does not add any additional information. The object of the data compression process is to eliminate the redundant data in order to allow the essential data to be retained much farther back in time from the accident. The goal is to record basic data for at least 30 minutes prior to the accident.

The following paragraphs describe the data compression techniques studied. The approach taken in this presentation is to first describe the fundamental compression procedure proposed, and then describe in more detail the alternative implementations and variations of this basic procedure. The advantages and disadvantages of each specific technique are discussed, and the effectiveness of each is evaluated. The effectiveness is determined by the use of actual data available from the flight evaluation of a Hamilton Standard ARINC 573 flight data recording system flown by Sikorsky Aircraft on a YCH-53E helicopter. This flight evaluation data is described in Appendix A. This test flight included most of the parameters considered in this study, except attitude.

Floating Limit Data Compression Procedure

The basic data compression philosophy, which is fundamental to the specific techniques studied, is based on the concept of a floating limit. Much data storage space is wasted by continuing to record a parameter that is not changing or that is changing very slowly. The floating limit technique eliminates this redundant data by saving the last recorded value of a parameter and only recording it again if it changes from the last value by more than some specified limit. A typical example of the application of floating limits is shown in Figure 18, taken from actual flight data on the YCH53E helicopter. The size of the limit will be a trade off between the accuracy desired for the recorded parameter and the amount of compression achieved.

FIGURE 18. TYPICAL EXAMPLE OF FLOATING LIMIT RECORDING

The example shown has a relatively large limit to clearly illustrate the floating limit concept. The limit can be made smaller such that on a plot like Figure 18, the two curves would be almost indistinguishable while providing a large degree of data compression.

Several factors must be considered in the development of the floating limit data compression techniques. Two major considerations are the choice of the floating limit and the organization of the data in the memory.

Size of the Floating Limit

The size of the floating limit is basically a function of the requirements of the accident investigators to accurately follow each particular parameter. The basic values assumed for the limits were determined by discussion with Army accident investigation personnel as discussed in Section 3. These basic limits are given in Table 4. These limits were used as a reference, and the effects of variations in these limits were evaluated both in terms of the accuracy of following the actual signal and amount of compression. This evaluation was performed on the parameters that were available from the flight test program discussed in Appendix A. A nominal sampling rate of once per second was used.

Example altitude and airspeed plots of raw YCH53A data and the floating limit data are both plotted together, as shown in Figures 19 through 24. The combined plot for all parameters is given in Appendix A. It can be seen from the plot that altitude is reproduced very accurately; airspeed is not followed as accurately.

The amount of data compression as a function of the limit is shown in Table 22. Plots of samples versus the magnitude of the limit for several of the parameters is given in Figures 25 to 30. It can be seen from the table and plots that the basic limits are very nearly at the most effective level. For example, Figure 25 shows that a 50-foot limit on altitude is just below the "knee" of the curve. Limits below 30 feet cause the number of samples to increase rapidly because these limits begin to allow sensor noise and pressure fluctuations, particularly in hover, to cause a large number of altitude samples to exceed the limit. Thus, a limit between 30 and 50 feet is most effective to assure that all significant changes in altitude are recorded without recording noise.

The number of samples needed to record airspeed is much less. The limit could be lowered from 15 to 10 knots, with only an increase from 52 to 86 samples for this 40-minute flight. This limit would give a more accurate representation of the airspeed. The composite plot of airspeed with a 10-knot limit is shown in Figure 31.

The 5% limit for rotor speed and engine torque is seen to be an efficient level. The 10% level is also efficient for the control position parameters. The effect of noise is well illustrated by the difference between lateral cyclic and pitch cyclic. This difference can be seen in the plots in

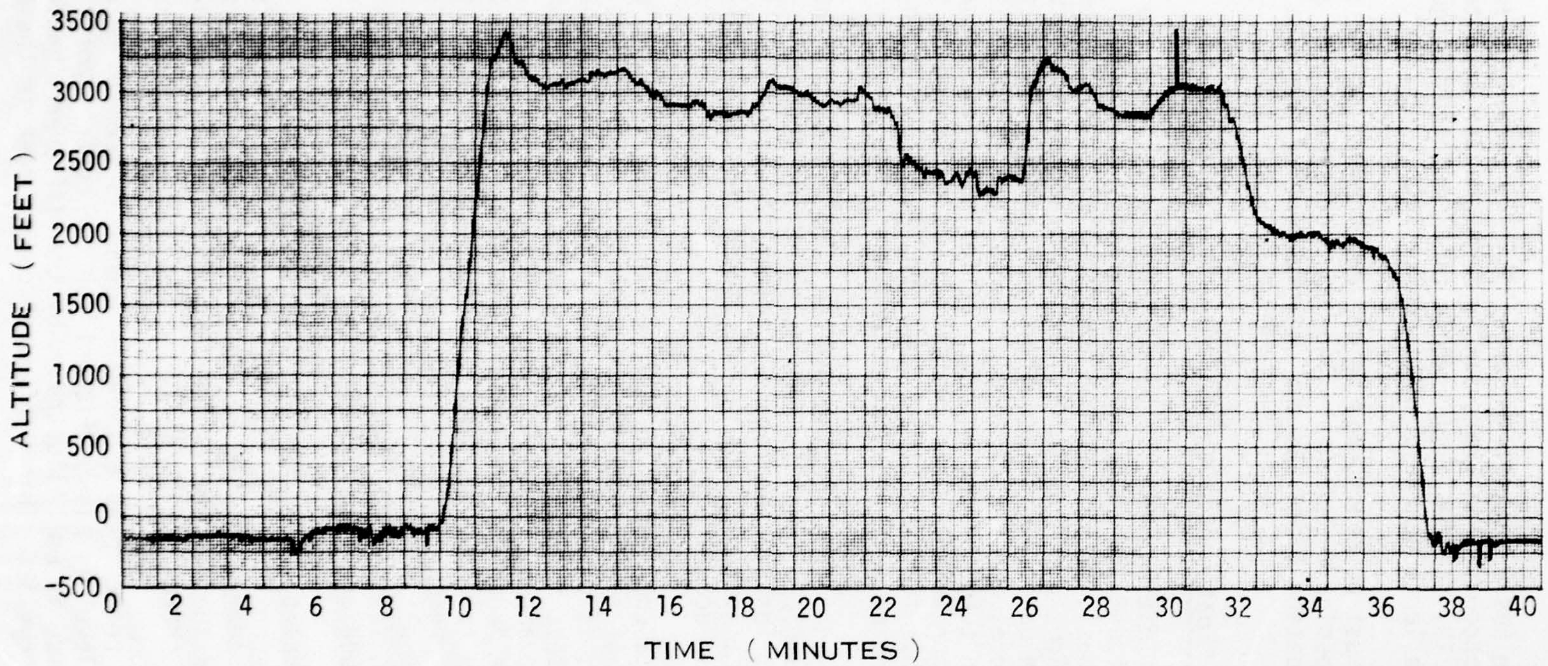

FIGURE 19. RAW ALTITUDE DATA

AD-A055 590 UNITED TECHNOLOGIES CORP WINDSOR LOCKS CONN HAMILTON --ETC F/G 1/2
PRELIMINARY DESIGN OF AN ACCIDENT INFORMATION RETRIEVAL SYSTEM --ETC(U)
APR 78 H R ASK, M E MOFFATT, I HUGHES DAAJ02-76-C-0058
UNCLASSIFIED HSER-7342 USARTL-TR-77-51 NL

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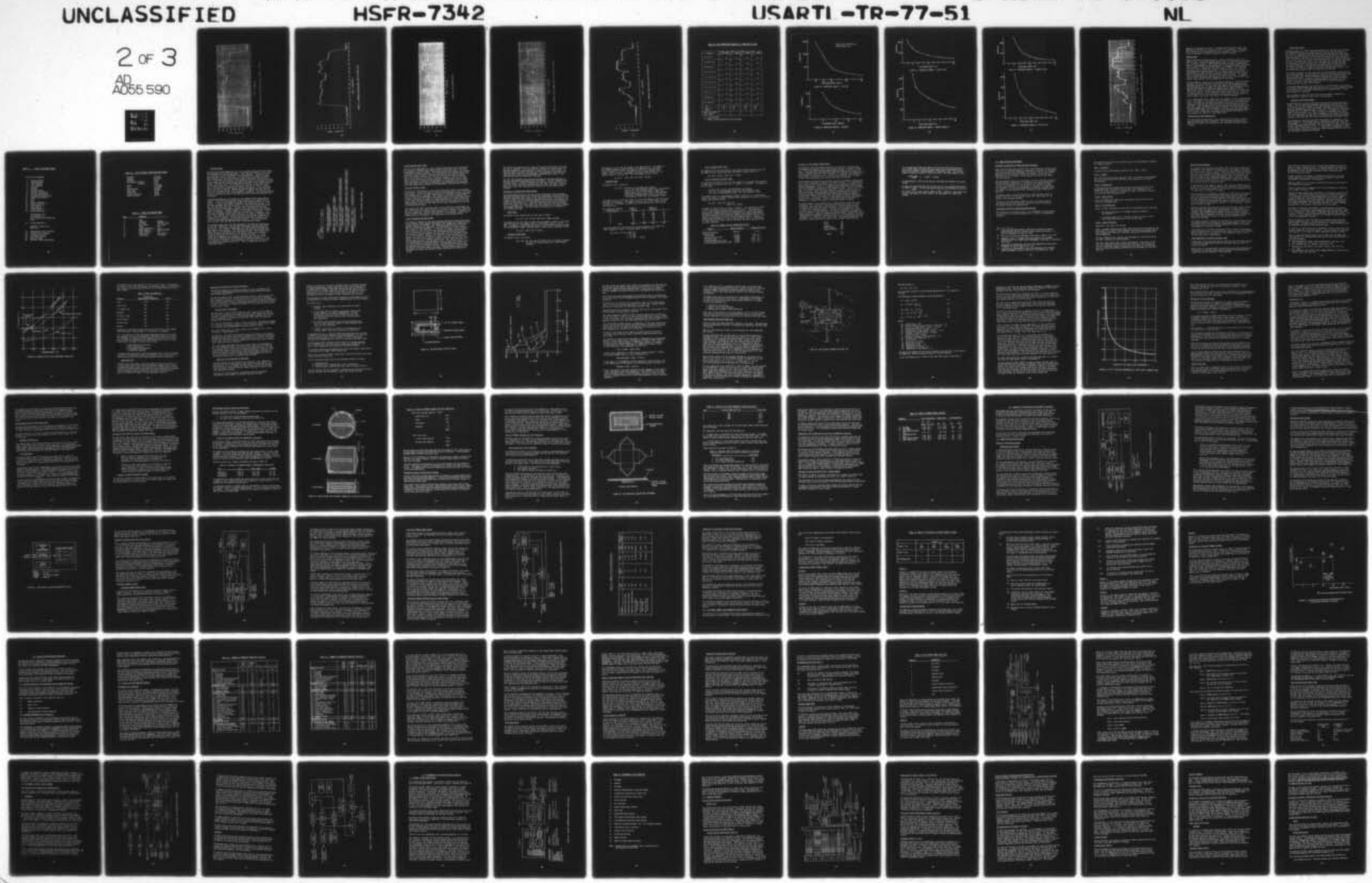
A055 590



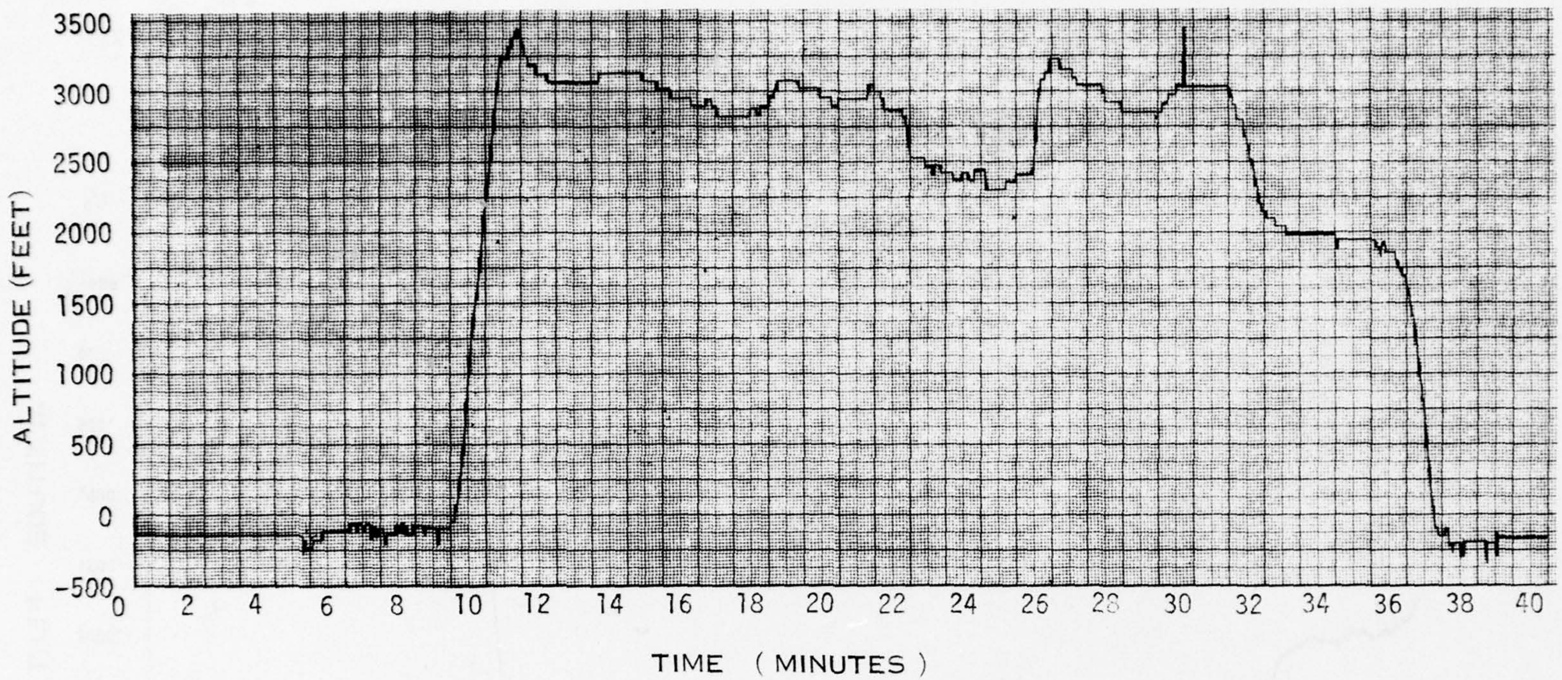


FIGURE 20. FLOATING LIMIT ALTITUDE DATA PLOT (LIMIT - 50 FEET)

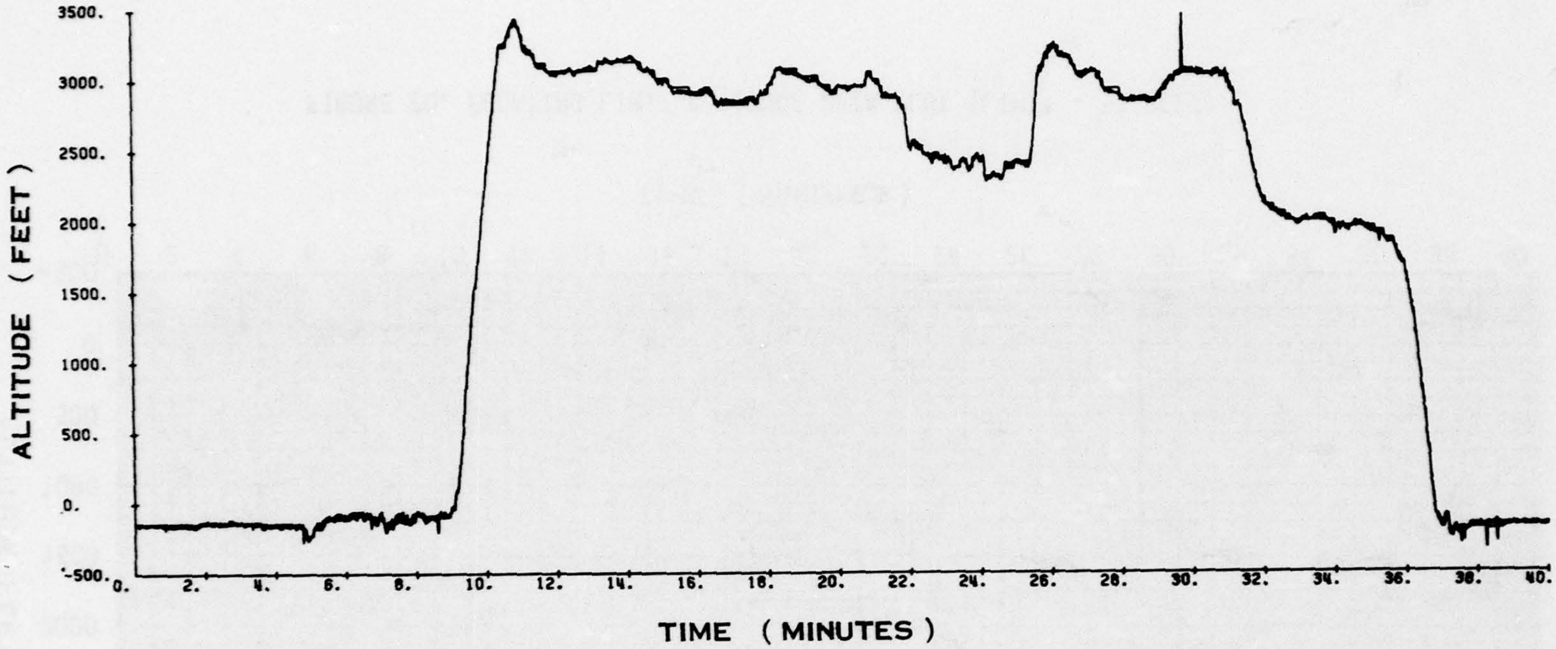


FIGURE 21. COMBINED RAW/FLOATING LIMIT ALTITUDE PLOT

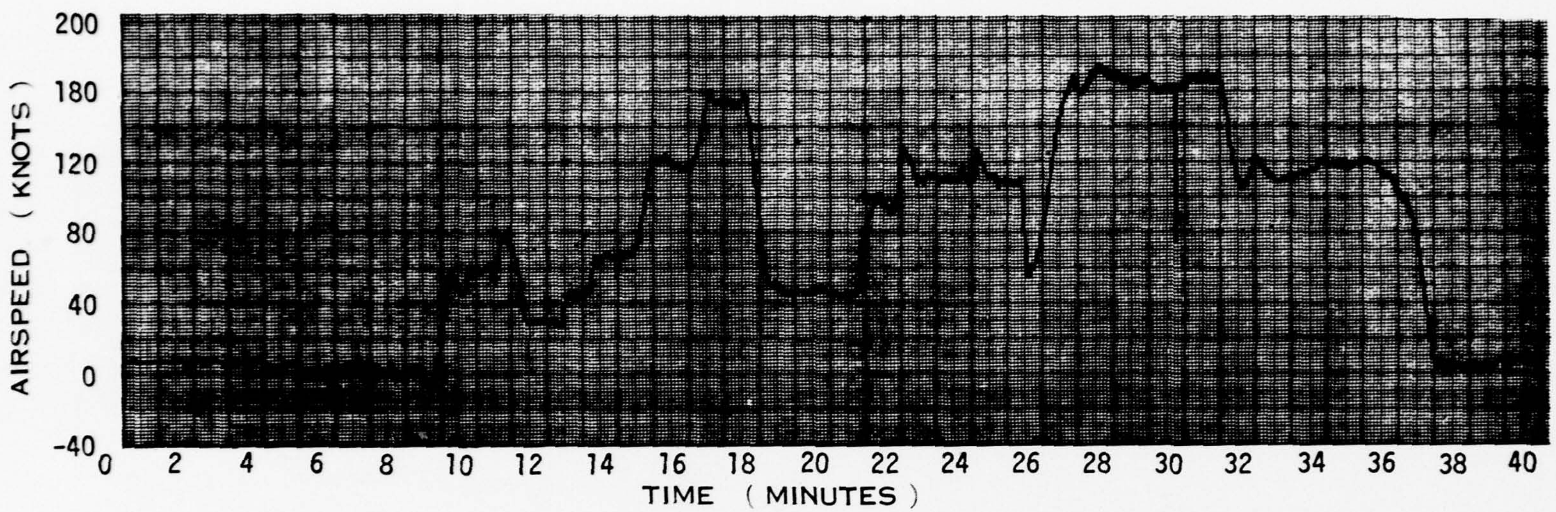


FIGURE 22. RAW AIRSPEED DATA

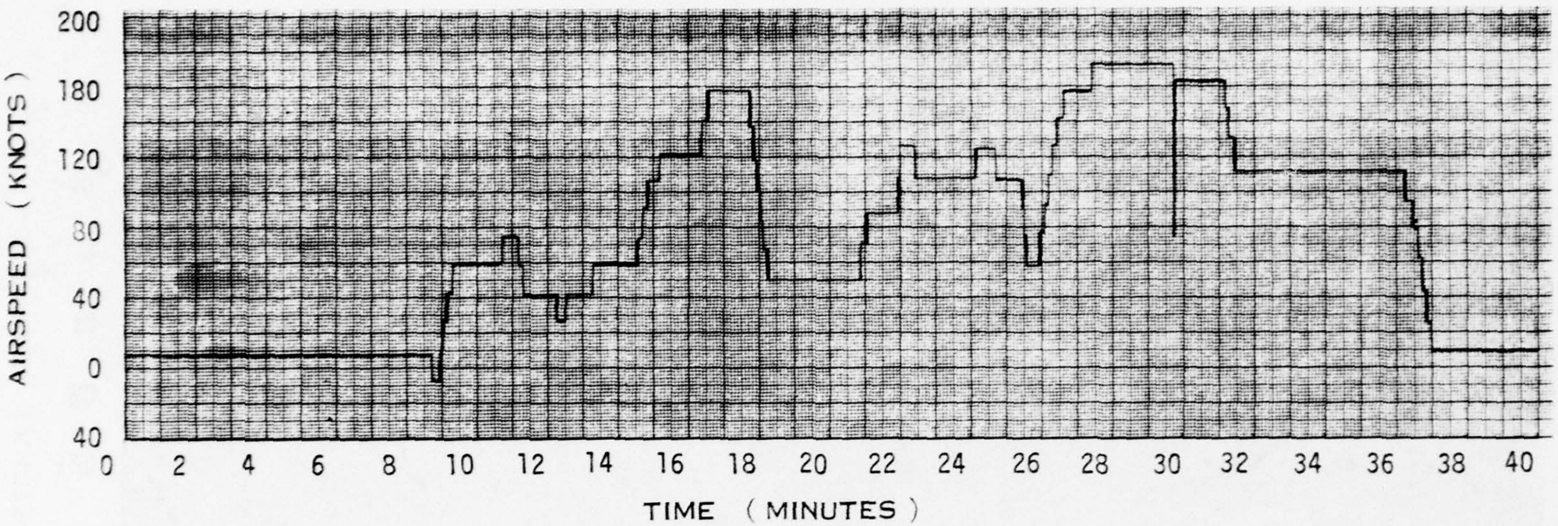


FIGURE 23. FLOATING LIMIT AIRSPEED DATA PLOT (LIMIT 15 KNOTS)

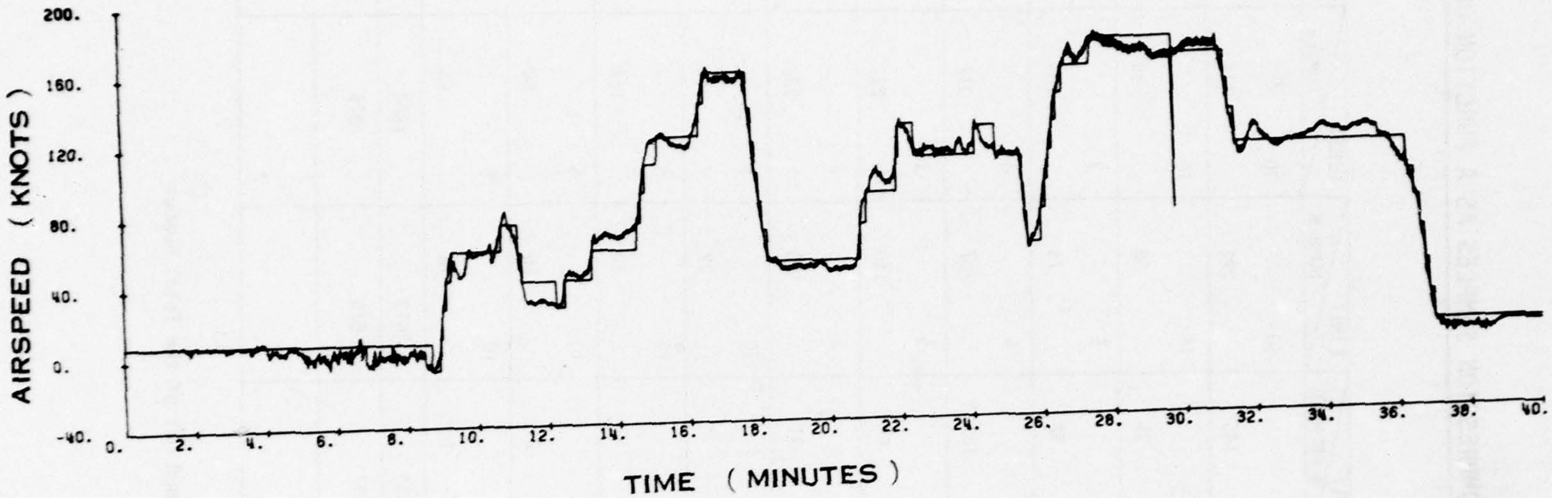


FIGURE 24. COMBINED RAW/FLOATING LIMIT AIRSPEED PLOT

TABLE 22. DATA COMPRESSION SAMPLES AS A FUNCTION OF LIMIT

PARAMETER	*LIMIT	**NUMBER	LIMIT	NUMBER	LIMIT	NUMBER	LIMIT	NUMBER
1 Altitude (Ft)	70	145	50	222	30	474	20	848
2 Airspeed (Knots)	20	35	15	52	10	86	5	205
3 Rotor Speed (%)	10	32	5	75	3	106	2	141
4 Eng. Torque #1 (%)	10	107	5	207	3	317	2	442
5 Eng. Torque #2 (%)	10	65	5	140	3	227	2	330
6 Eng. Torque #3 (%)	10	91	5	193	3	332	2	441
7 Lateral Cyclic (%)	15	9	10	22	5	66	3	138
8 Pitch Cyclic (%)	15	19	10	38	5	127	3	246
9 Collective (%)	15	21	10	46	5	90	3	148
10 Yaw Pedals (%)	15	10	10	18	5	55	3	110
Total	534		1013		1880		3049	
Times With Change	407		670		1076		1507	
Total No. of Samples Used (2400)								

* = ± Limit Value Used

** = Number of Samples Retained Out of the Total Number

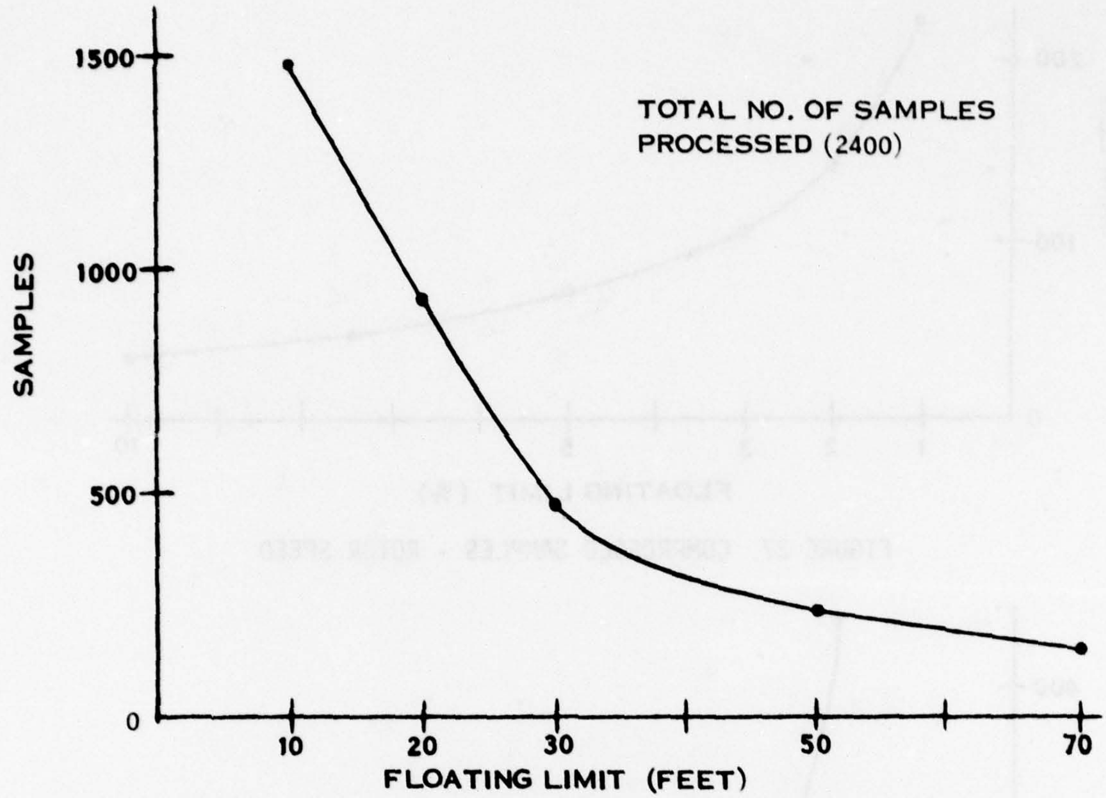


FIGURE 25. COMPRESSED SAMPLES - ALTITUDE

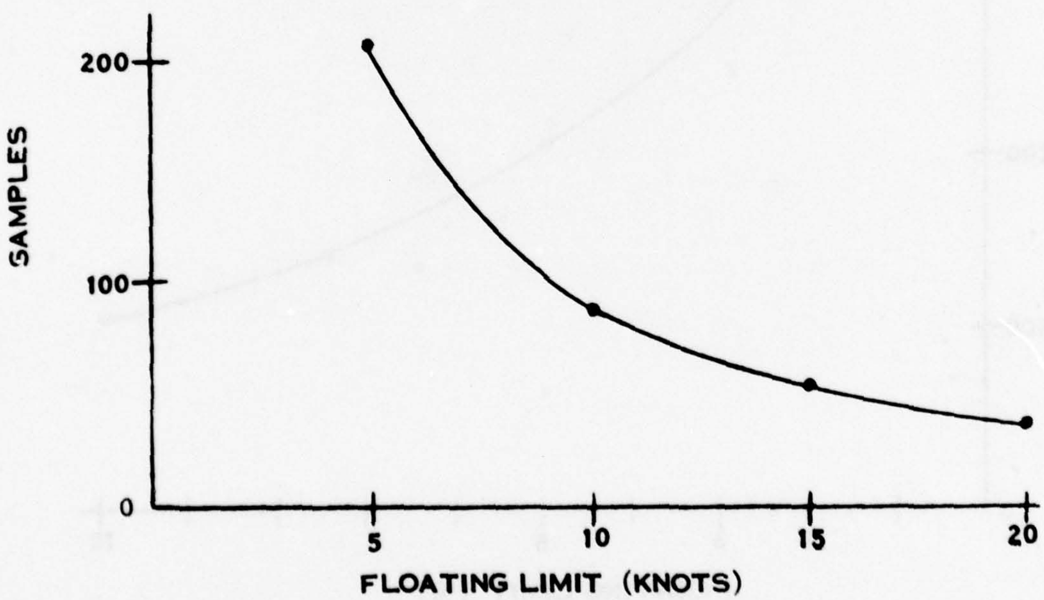


FIGURE 26. COMPRESSED SAMPLES - AIRSPEED

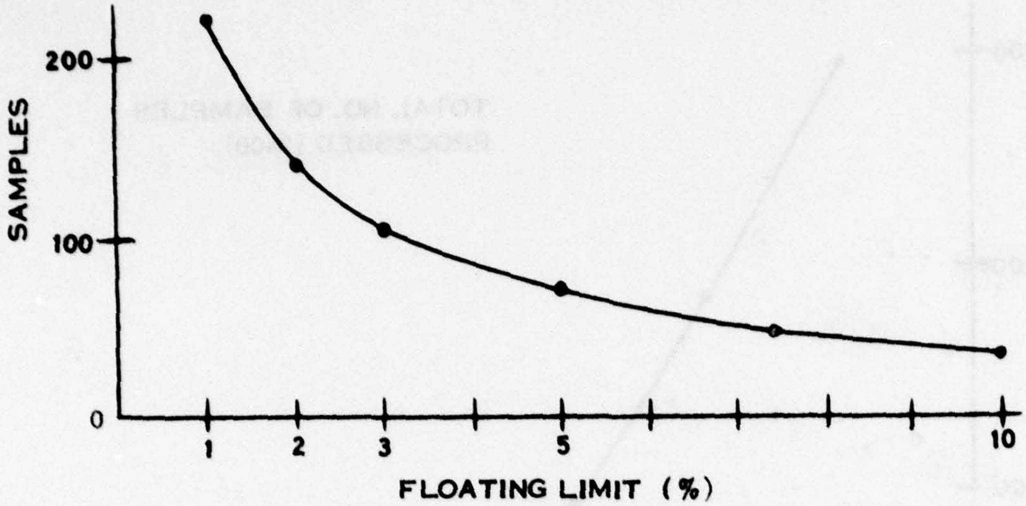


FIGURE 27. COMPRESSED SAMPLES - ROTOR SPEED

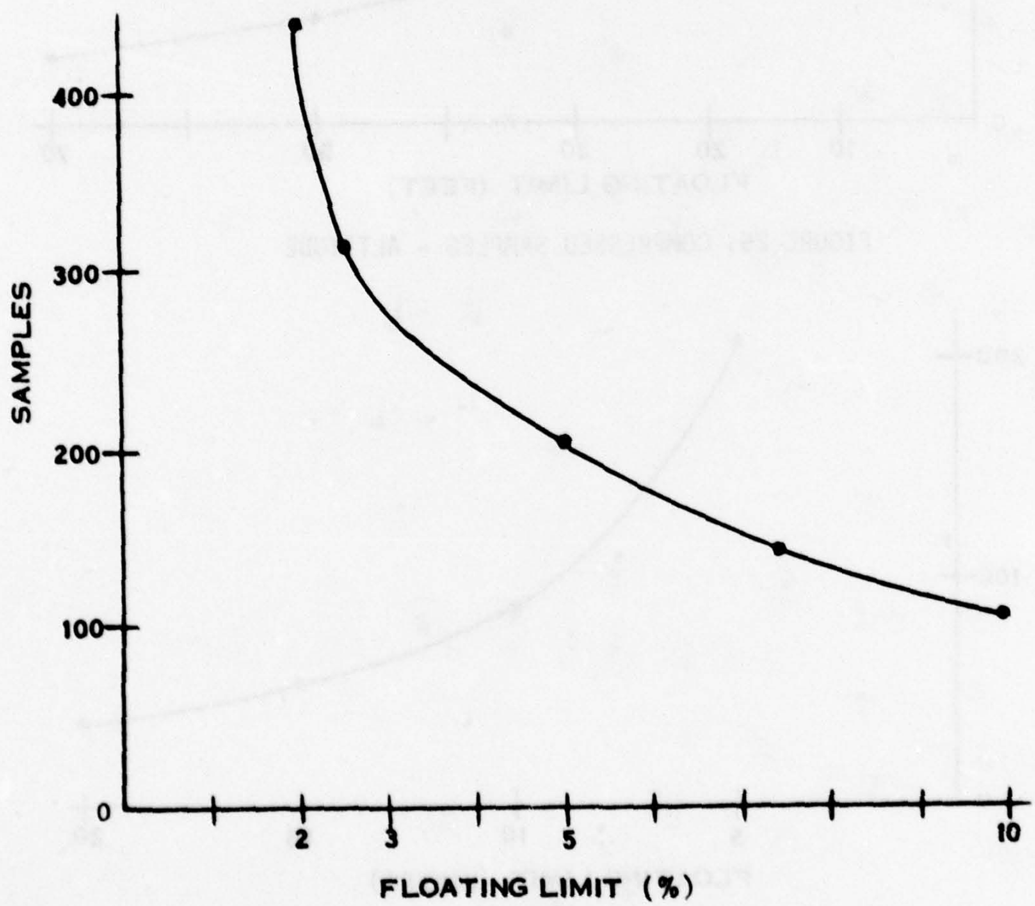


FIGURE 28. COMPRESSED SAMPLES - ENGINE TORQUE #1

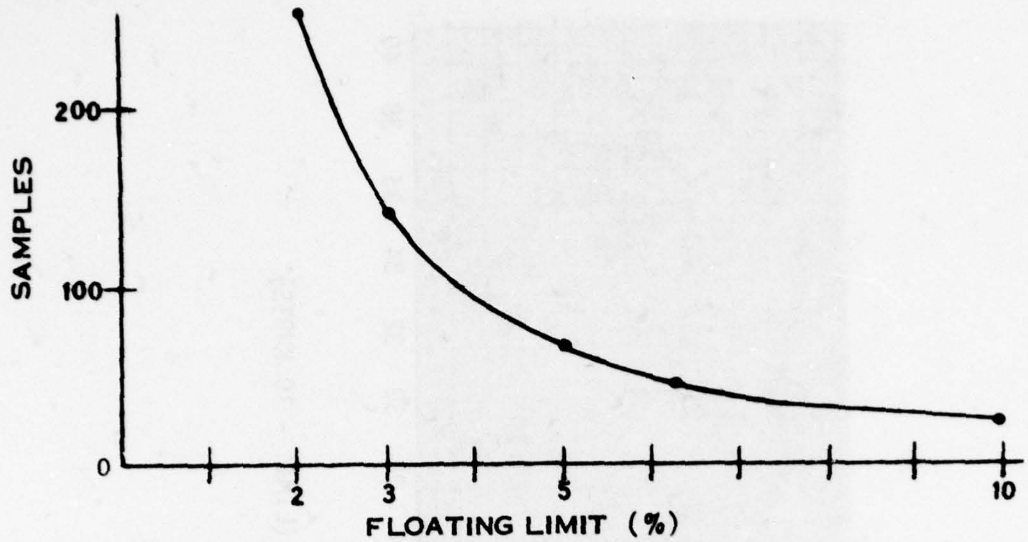


FIGURE 29. COMPRESSED SAMPLES - LATERAL CYCLIC

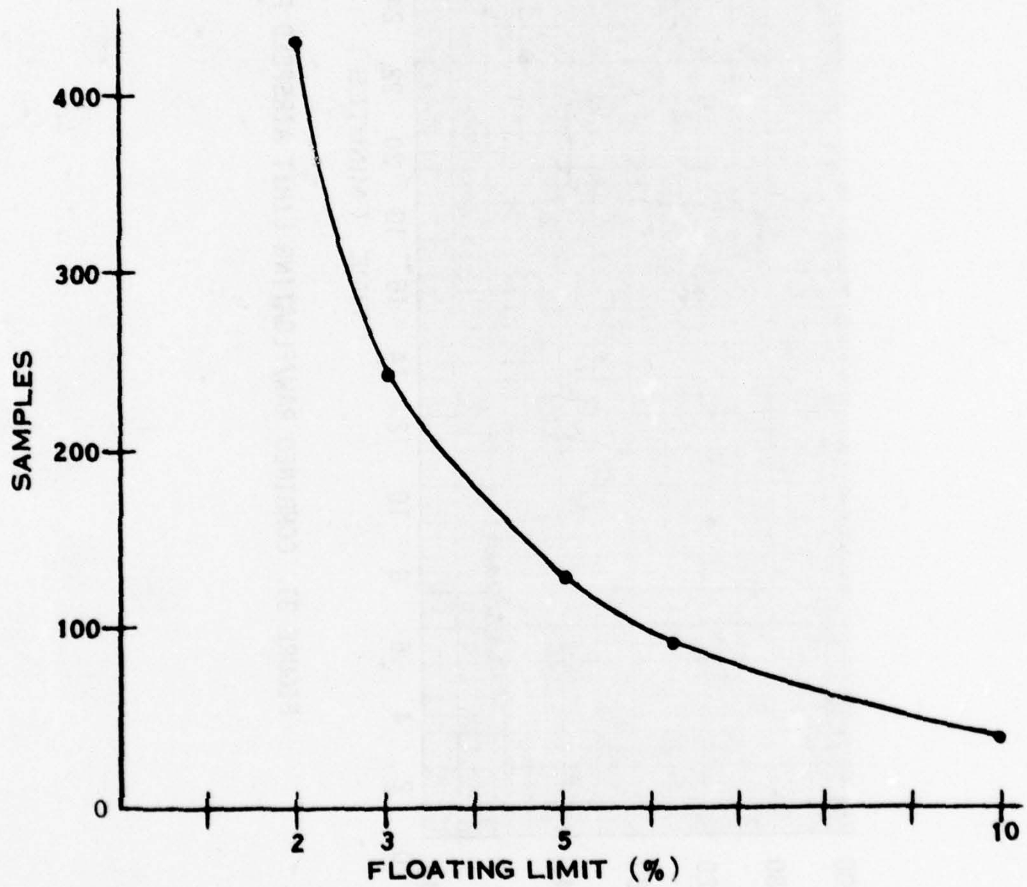


FIGURE 30. COMPRESSED SAMPLES - PITCH CYCLIC

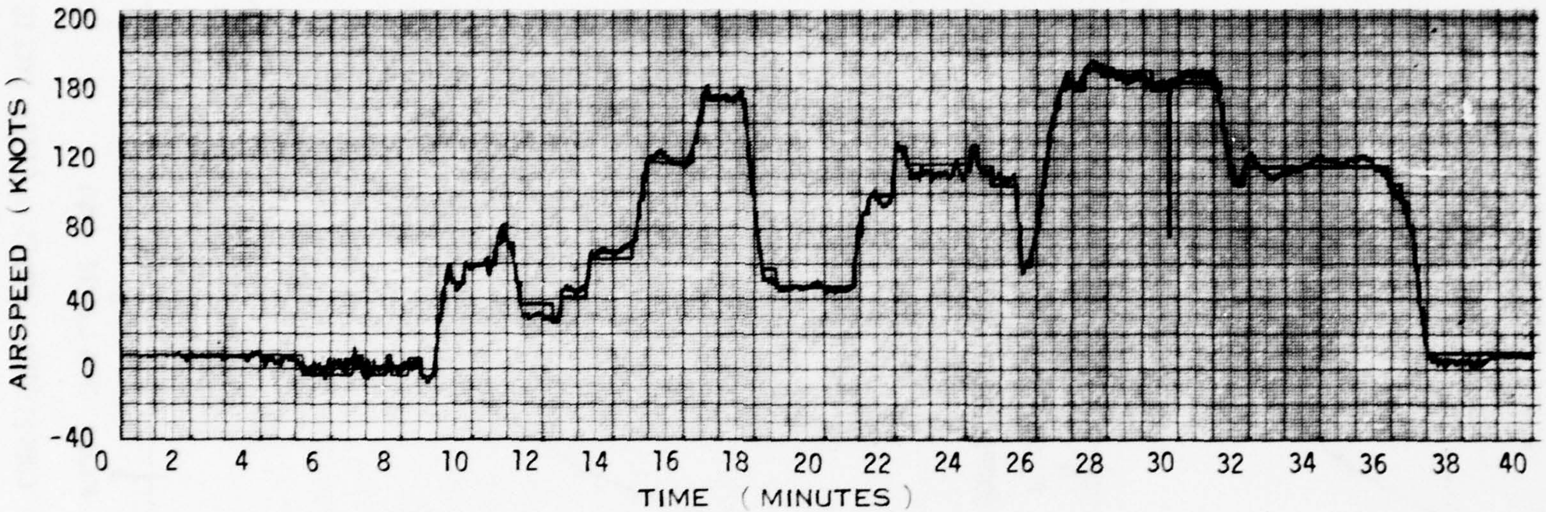


FIGURE 31. COMBINED RAW/FLOATING LIMIT AIRSPEED PLOT (LIMIT - 10 KNOTS)

Appendix A (Figures A-7 and A-8). Although both signals are noisy, the magnitude of the noise for the pitch cyclic is much greater. The greater noise results in the much greater rise in the number of samples as the limit is decreased, as shown by comparing Figures 29 and 30.

Sampling Rate

Another important consideration that is clearly related to limit size is sampling rate. The maximum sample interval that is considered to be acceptable is given in Table 4. When floating limits are used, a significant measure of the adequacy of the sample rate is the maximum rate of the parameter in terms of limit values per sample. For example, if altitude has a 50-foot limit, a 3000-ft/min vertical speed will have a one limit per sample rate at one sample per second. If the vertical rate is greater than 3000-ft/min, the uncertainty in the altitude between samples will be greater rates in terms of limit values per sample interval. An attitude rate of 40 degrees/sec will be four limit values per second. A complete engine failure can cause engine torque to fall to zero in as little as one second. Many controls can be changed 100% in one second.

The requirement to record in detail the exact values of a rapidly changing parameter must be determined in coordination with those responsible for analyzing accidents. For this study four samples per second was assumed for acceleration and one sample per second for all other parameters. This sampling rate meets or exceeds the maximum sample intervals given in Table 4 and is also very near the current one required by civil regulations as shown in Table 3. These regulations require one sample per second for most parameters with four per second for acceleration, two per second for rudder pedals, and one per four seconds for engine parameters.

If it is determined that a higher rate is necessary, it can be accomplished with little impact on the complexity of the system or on the memory requirements. The impact of increasing the sample rate to twice per second was evaluated on the YCH-53E flight test data for engine torque and control positions. These parameters will give the worst case results because they have the highest rate of the parameters available. The result was that increasing the sample rate by a factor of two increased the memory requirements by 15% or, conversely, the memory would contain approximately 15% less average real time for a fixed memory size.

Proposed Data Frame Organization

The other major consideration is the organization of the data in memory. Several alternatives were considered. The following paragraphs give a description of each of the formats and the advantages and disadvantages of each.

Fixed-Frame Format

The basic format is a fixed frame which contains all the data to be recorded. The complete frame that is assumed for this study is given in Table 23. The 16 bits of synchronization are necessary to assure that the band boundaries and the beginning of the frame can always be identified in the serially organized memory, even when there are data bit dropouts or power interruptions. The 16 bits are chosen so that the probability that they are duplicated in data is extremely low. When a full data frame only is recorded, two words are necessary to uniquely define time. Altitude also requires two words plus one discrete bit. Discrete bits are packed into two separate words. The frame is defined to include one spare word and four spare discretes to increase the ability to adapt the system to different helicopters. The spare word may be used for EGT if its use can be justified.

The primary advantages of the fixed frame are simplified data processing and time correlated data. Since the data is always in the same relative position and in the same form, the data reduction on the ground is more straightforward and reliable. Since all of the parameters are recorded at nearly the same time, the relationship between parameters can be more precisely known. For example, the control positions can be correlated with the attitude angles, airspeed, and altitude.

The primary disadvantage of the fixed frame is the inefficeint use of memory. If the whole frame is recorded every time and only one or two parameters exceed their limits, all of the other parameters must be recorded even if little new information is obtained.

Using the basic limits with the flight data described in Appendix A, a data compression factor of only 3.6 to 1 was achieved.

Two-Level Fixed-Frame Format

An alternative to the one fixed-frame format would be to have two fixed frames. The full data frame would be recorded only when the most significant four bits of the floating limits were exceeded. The discrete bits would be included only in the full frame. The values for the limits for recording the full frame are given in Table 24. The format of the reduced frame is given in Table 25. Time in minutes is considered like a most significant parameter in that, when it changes, a full frame is recorded. This full frame once per minute will be sufficient to provide the synchronization so that the sync bits can be eliminated from the reduced frames.

The advantage of using the two-level frame format is a reduction in the memory required. The reduced frame is recorded only when the basic limit is exceeded. It is less than half the size of the full frame. The full frame is recorded much less often. The data reduction using this technique on the sample flight data is 4.7 to 1. The primary disadvantage is that the data reduction process becomes more complex because different data must be correlated to reconstruct the data.

TABLE 23. BASIC FIXED-FRAME FORMAT

Word (8 bit)	Parameter
1	Synchronization
2	Synchronization
3	Time (minutes)
4	Time (seconds)
5	Airspeed
6	Heading
7	Altitude (Code)
8	Altitude (Transducer)
9	Vertical Acceleration
10	Longitudinal Acceleration
11	Lateral Acceleration
12	Pitch
13	Roll
14	Engine Torque No. 1
15	Engine Torque No. 2
16	Rotor RPM No. 1
17	Engine RPM No. 1
18	Engine RPM No. 2
19	Discrete Word No. 1
	Chip Detector (4)
	Fire Detector (2)
	Most Significant Altitude Bit
	Spare
20	Discrete Word No. 2
	Hydraulic Pressure (3)
	Spare (3)
21	Longitudinal Cyclic Position
22	Lateral Cyclic Position
23	Collective Position
24	Yaw Pedal Position
25	Radar Altitude
26	Vertical Flight Acceleration

TABLE 24. LIMITS FOR MOST SIGNIFICANT HALF WORDS

Airspeed	25 knots
Heading	22.5 deg
Altitude	320 ft
Acceleration (Flight)	0.62g
(Impact)	9.4g
Pitch	11.25 deg
Roll	11.25 deg
Engine Torque	18.8pct
Rotor RPM	18.8pct
Engine RPM	15pct
Control Positions	12.pct
Radar Altitude	125 ft

TABLE 25. FORMAT FOR REDUCED FRAME

WORD	PARAMETER	
1	Time	
2	Airspeed	Heading
3	Altitude	Vertical Accel.
4	Long. Accel.	Lat. Accel.
5	Pitch	Roll
6	Engine Torque No. 1	No. 2
7	Rotor RPM No. 1	Radar Altitude
8	Engine RPM No. 1	No. 2
9	Long. Cyclic	Lat. Cyclic
10	Collective	Yaw Pedal

Variable Frame

The next step in data reduction is to use a variable frame which only records the parameter that exceeded the limit. Since the frame format is not fixed, it is necessary to add an identifier to each parameter. The time of each parameter must also be identified. It is necessary to construct a format that assembles this data into eight-bit words in the most efficient way in order to minimize the overhead. The synchronization bits and time in minutes are recorded once per minute so that they do not have to be recorded with each sample. The data can be packed much more efficiently if the identification can be made in four bits. It is possible to identify the data with four bits if acceleration is handled as a special case and if a bit is included within the data to identifiy whether an engine parameter is associated with the first or second engine. This procedure will require that the EGT resolution be increased to 13°F, which should be acceptable. The data organization will also be more efficient if the same time word is used for multiple limit exceedances.

Using these guidelines, the format for the variable frame is described as follows. The 16-bit sync word and time, in minutes, are recorded once per minute. If one or more parameters exceed their floating limits in a given second, a variable data frame is recorded. The first word contains a six-bit time word and a two-bit word count. The next word contains one or two four-bit identification codes. The next one or two words are the data. These words can be followed by another set of identification codes and data words if necessary. The data format is illustrated in Figure 32. If more than four parameters change at one time, the time word is repeated. The zero time in seconds is not used as time but as a code to indicate acceleration. The other two bits in the first word indicate which component of acceleration is recorded. The next whole word is time in seconds, which allows for the required quarter-second resolution. The next two words give the peak value and time-over-limit in that quarter second.

The variable frame format has the advantage of increasing the efficiency of the data compression. For the same flight data, the data compression was 25 to 1. The primary disadvantages are identification overhead and more complex data recovery. Four extra bits are required with each parameter that is not required in the fixed-frame format. The variable-frame format increases the complexity of the recovery program and slightly increases the possibility of errors in decoding the data. It is not likely that parameters are recorded at the same time, making it more difficiult to determine the interrelationship between parameters. It is also difficult to maintain high confidence in the status of a signal that is recorded very seldom or not at all. There is always the fear of an undetected failure.

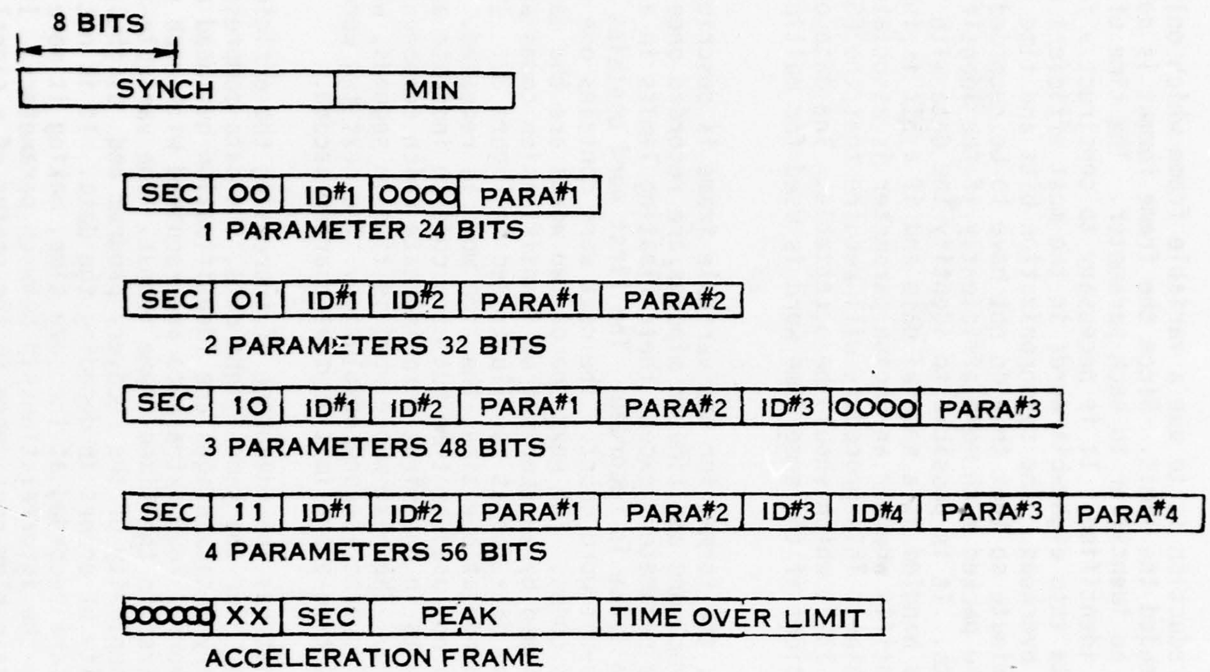


FIGURE 32. VARIABLE-FRAME FORMAT

Fixed Frame/Variable Frame

Some of the disadvantages of a pure variable-frame format can be alleviated by including a complete fixed frame of data at a periodic rate. The rate recommended is once per minute. The format would be the same as the variable frame just discussed except that at the one-minute rate the whole data frame would be recorded instead of just the sync bits and the time in minutes. These fixed frames will add only 184 bits per minute of 11K bits per hour. They have the advantage of giving a periodic reference point for all parameters and greatly increasing the confidence in the floating limit values. The fixed frames also allow all parameters to be compared at the same time. These advantages should outweigh the disadvantage of the additional memory.

Two-Level Variable Frame

The two-level representation of the data could also be used in the variable-frame format. The entire parameter would be recorded when the most significant bits changed and only the least significant bits recorded at other times when the floating limit is exceeded. This format is difficult to organize efficiently. One of the bits that was previously used as word count must be used to indicate whether the sample is a most significant or a least significant frame. Also, in order to retain the efficiency of using only four bits for identification, one of the four data bits for engine parameters must be used to indicate which engine.

This reduces the least significant part to only three bits, which makes the most significant part almost the same as the basic floating limits themselves and this essentially eliminates one advantage of this method. Because of the greater complication, greater inefficiencies in the overhead, and the small potential gain in efficiency, this format was not considered further.

Fixed Frame/Delta Variable Frame

This format is similar to the fixed-frame/variable-frame format except that in the variable frames between one-minute fixed frames, only changes and not absolute values are recorded. The changes are represented by three bits. One for sign and two for magnitude. One magnitude bit is equal to the limit value for that parameter. If the rate of change of the parameter is slow relative to one limit value per second, the output from this method will be essentially the same as the fixed-frame/variable-frame format. As the rate of change increases, the parameter value at the sample times will be less precise. However, the value will always be within the limit bounds unless the rate of change is greater than four limit values per second. If the rate of change is greater than four times the limit value, the recorded value will lag the actual value. This characteristic will only be important for those parameters that can change very rapidly, such as control positions and engine torque. The maximum values which could be recorded using the nominal limits are 20% per second for engine torque and 40% per second for control positions. Maximum heading rate would be 40 degrees per second and maximum attitude rate would be 20 degrees per second.

The limited rate problem can be solved by reverting to the whole value when the rate is exceeded. A tag bit would be included with the time word to indicate whether the frame represents a whole value or a delta value. The other bit would be used to indicate one or two parameters associated with that time word. More than two parameters exceeding their limits in one second would require an additional time word.

The rate limit problem could also be alleviated by nonlinear weighing of the bits representing the magnitude of the change. Two bits represent four different values. Instead of representing one, two, three and four times the limit value, they could represent one, two, four, and eight. When the change was large, this technique would reduce the lag but would be less accurate.

Evaluation of Compression Effectiveness

The effectiveness of each of the data frame organizations was evaluated by applying the appropriate factors to the limit exceedance information derived from the flight test data. Most of the information used in the analysis is listed in Table 22. The following paragraphs give the basic calculations for determining the number of bits that would be required for each technique to record the flight test data. Since the flight test data does not include the full parameter list, the results are used primarily as a relative comparison between techniques. The total memory requirements are estimated in the following sections.

Fixed Frame

The number of bits required for the test data is simply:

No. bits = No. bit per frame X No. frames recorded

The number of bits per frame is eight times the number of words in the frame given in Table 18. The number of bits in the frame is thus 8 X 26, or 208. The number of frames recorded out of a possible 2400 one-second frames for the 40-minute flight, using the nominal limits given in Table 22, is 670.

No. bits = 208 X 670 = 139,360

Two-Level Fixed Frame

The number of bits is given by:

No. bits = No. bits per full frame X No. full frames recorded + No. bits per reduced frame X No. reduced frames recorded

The number of bits in the full frame is the same 208 bits. The number of full frames recorded for the CH53 data was computed, using the limits listed in Table 18, as 258. The number of bits in the reduced frame shown in Table 24 is 80. The number of reduced frames recorded for the nominal limits is the same 670. The total number of bits is thus:

No. bits = 208 X 258 + 80 X 670 = 107,264

Variable Frame

The number of bits is given by:

No. bits = No. bits in sync frame X No. minutes + No. bits in one-parameter frame X No. one-parameter frames + No. bits in two-parameter frame X No. two-parameter frames + No. bits in three-parameter frame X No. three-parameter frames + No. bits in four-parameter frame X No. four-parameter frames

The number of bits in the sync frame is 24, and the length of the test flight data used in 40 minutes. The number of bits in each of the frames is given in Figure 32. The number of frames with single and multiple limit exceedances was to be:

No. Parameters Changing In One Second	Number of Indices	%	Number of Parameter	%
1	446	66	446	44
2	132	20	264	26
3	71	11	213	21
4	15	2	60	6
5	6	1	30	3
6	0	0	0	0
TOTAL	670	100	1013	100

Since one frame will contain only up to four parameters, the number for five is added to 1 and 4. The total number of bits is thus:

No. bits = 24 X 40 + 452 X 24
+ 132 X 32
+ 71 X 48
+ 21 X 56 = 20,616

Fixed Frame/Variable Frame

The number of bits for this format is the same as the previous one plus the 184 added bits per fixed frame times the time in minutes, which is:

$$\text{No. bits} = 20{,}616 + 184 \times 40 = 27{,}976$$

Fixed Frame/Delta Variable Frame

In computing the number of bits for this format it is assumed that the number of times that the maximum slew rate is exceeded is negligible. The number of bits are thus:

No. bits = No. of bits in fixed-frame X No. minutes
+ No. bits in one-parameter-frame X No. one-parameter frames
+ No. bits in two-parameter frames X No. two-parameter frames

The number of bits in a one-parameter frame is 16 and 24 in a two-parameter frame. The number of frames is derived from information given with the variable-frame analysis, which gives:

$$\text{No. bits} = 208 \times 40 + 523 \times 16 + 245 \times 24 = 22{,}568$$

A summary of these results is given in Table 26. The significant savings in using some form of variable frame is easily seen. The technique of using a fixed-frame/variable-frame format appears to be the best compromise between software complexity and hardware data storage requirements. The added information and reliability added by the once-per-minute fixed-frame is considered to be well worth the additional memory. However, in systems where the memory is very limited or where there is a requirement to record data for as long a time as possible, the delta frame would be a very good candidate.

TABLE 26. SUMMARY OF DATA COMPRESSION RESULTS

FORMAT	MEMORY REQUIRED	COMPRESSION RATIO
Constant Recording	499,200	1 to 1
Floating Limit		
Fixed-Frame	139,360	3.58 to 1
Two-Level Fixed-Frame	107,264	4.65 to 1
Variable-Frame	19,656	25.4 to 1
Fixed-Frame/Variable-Frame	27,976	17.84 to 1
Fixed-Frame/Delta-Variable-Frame	22,568	22.1 to 1

Estimate of Total Memory Requirements

An estimate of the total memory required as a function of time was made to determine the capacity of the various memory options in terms of flight time. The fixed-frame/variable-frame format was used as a basis for this effort. Unfortunately, the available flight test data did not include all of the parameters on the basic list. However, it is possible to estimate the total memory requirements by using an available parameter that is judged to have similar characteristics to the ones that are missing.

The parameters missing from the previous analysis are heading, acceleration, roll, pitch, engine RPM, discretes, and radar altitude. It is assumed that the discretes do not change often enough to have significant impact on the memory requirements. Also, it is assumed that acceleration will be above the limit threshold only during a small amount of time. For the test flight data, if vertical acceleration was recorded to within an accuracy of 0.1g when it was over 1.25g, only approximately 40 samples would be required, giving an average of approximately one sample per minute per channel. Accelerations above 0.25g in the other two channels would be expected to be much less. Flight acceleration is thus assumed to require only approximately 24 bits per minute. Impact accelerations would be recorded for fractions of a second and requires a negligible amount of memory.

Airspeed (Figure 21) was judged to be a rough estimate of the variations in heading, roll, and pitch. The floating limits were chosen to cover the dynamic range with the required accuracy. These assumptions were: a 15-knot limit represents pitch, a 10-knot limit represents roll, and a 5-knot limit represents heading. The nominal helicopter was assumed to have two engines. Since the flight test data involved three engines, one engine torque was assumed to represent the other engine. Radar altitude was represented by a barometric altitude; however, it is assumed that the radar altimeter is in range only half of the time. Using these assumptions, the additional samples that must be added to the recorded flight data are:

Pitch	52
Roll	86
Heading	205
Engine Speed	140
Radar Altittude	100
TOTAL	583

It is assumed that these new samples will have the same distribution as the original samples so that the total memory can be estimated by multiplying the previously computed memory by the proper ratio. The original number of samples is given in Table 22 as 1013. The total memory is thus:

$$\frac{1013 + 583}{1013} \times 27{,}976 = 44{,}077$$

or approximately 1,126 bits per minute, including the allowance for acceleration.

It should be noted here that the bit rate for all the candidate data points for AIRS is $\frac{1{,}126}{60} = 19$ bits per second compared to approximately 4,000 bits per second for one audio channel added to AIRS. Obviously, the digital data storage requirement for audio "dwarfs" the requirement for other data storage.

4.8 CRASH PROTECTION RATIONALE

Available Technology for Crash Recorder Packaging

Crash recorders have been carried in all large commercial aircraft since 1958, and a significant amount of technology is available for designing and evaluating protective packages. The survival rates of the recorder memories are also available to check the adequacy of both the test specifications for recorders and the success with which these specifications are met.

Absolute design criteria for survivability are not available because of the unpredictable combinations of mechanical and thermal damage that can occur. Any proposed test can be shown to be inadequate under certain crash conditions, so the design is necessarily a compromise. The compromise is very often determined by assigning a maximum weight and volume to the package and then including as much protection as possible.

The FAA has used a test specification for crash recorders which is updated from time to time, and this gives the firmest base for the design of new recorder packages.

The FAA has also sponsored a number of tests and studies aimed at evaluating recorder survivability. These are listed in References 26 through 30 and are discussed below.

Discussion of FAA Test Specifications TSO C51a

This discussion is limited to Para. 7.8 of Reference 26, which covers survivability of the recorder memory and is limited to nonejectable recorders.

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26 FLIGHT DATA RECORDER READOUT EXPERIENCE IN AIRCRAFT ACCIDENT INVESTIGATION, National Transport Safety Board, Washington, D.C. Rpt. No. NTSB-AAS-75-1, May 14, 1975

27 FIRE TEST CRITERIA FOR RECORDERS, FAA-DS-60-16 (NAFEC) July, 1970

28 PARAMETRIC STUDY OF THERMAL PROTECTION CONCEPTS FOR AIRBORNE RECORDED TAPES IN A SEVERE CRASH ENVIRONMENT, FAA-DS-69-11 (Sunstrand) Sept. 1969

29 EVALUATION OF INSULATION FOR CRASH FIRE PROTECTION OF NEW FLIGHT RECORDERS, FAA-RD-75 (NAFEC) Oct. 1972

30 EVALUATION OF EXPERIMENTAL FLIGHT DATA RECORDERS IN AN AIRCRAFT CRASH ENVIRONMENT, NA-68-24 (DS-68-23), FAA (NAFED) Nov. 1968

The specifications require the following tests to be performed in sequence on a sample recorder:

Item 1 - Humidity

6 cycles at 95 to 100% humidity from 38° to 70° (100° - 160°F)

Item 2 - Impact

Half sine wave impact shocks applied to each of the three main orthogonal axes with a peak acceleration of 1000 g and a duration of at least 5 milliseconds.

Item 3 - Penetration

A 500-pound steel bar dropped from 10 feet to strike each side of the memory enclosure in the most critical plane. The longitudinal axis of the bar to be vertical at the moment of impact. The point of contact to be no more than 0.05 square inch.

Item 4 - Static Crush

A force of 5000 pounds applied for five-minute cycles to each of the three main orthogonal axes.

Item 5 - Fire Protection

Flames of 1100°C enveloping at least half of the outside area of the case.

a. 30 minutes exposure for a recorder located at random in the aircraft.

b. 15 minutes exposure for a recorder located at least 1/2 wing cord length from the wing or from any fuel tank.

Item 6 - Water Protection

Immersion in salt water for 36 hours.

Items 1 through 6 (humidity and water immersion) are not too different from requirements for other military hardware. The humidity requirement can be met by coating the boards with conformal coating and using hermetically sealed components.

The water immersion test requires only the memory to survive and can be met with a hermetically sealed package.

The other items require more careful consideration. The purpose of the test is to reproduce crash conditions but, because of the variability of crash conditions, cannot be expected to be a guide to survivability under all crash environments, particularly with the onset of fire after the crash.

Typical Current Designs

The original crash recorders used metal tapes and engraved flight data parameters on the tapes with a diamond stylus. The number of parameters was limited. More recently, digital flight recorders (DFDR's) have been used to record many more parameters, and cockpit voice recorders (CVR's) have been used. Accident investigations have been facilitated by this additional data. Since a Mylar-base magnetic tape is generally used, the fire protection requirement for the package is more severe. Metal foil can survive 1970°F and 1150°F for steel and aluminum, respectively, while plastic tapes are limited to 300°F.

A side benefit of the magnetic tapes is that they are reusable and are simpler to record on. This has improved the reliability since the metal foil had to be replaced regularly, and failure to do so resulted in loss of flight data in a number of accidents.

Current recorders are generally rectangular in shape and are designed to fit in an aircraft electronics bay rack. Others have been made with spherical enclosures for maximum strength with minimum weight. It has been found difficult to stow them in an aircraft, their space factor is poor, and they are weakened by the place of separation which has to be at the spherical unit equator and which is very susceptible to mechanical failure on impact.

Ejectable recorders have been used on military aircraft. These recorders eject automatically when certain accelerations or temperatures are exceeded. They presumably have a better chance of survival than non-ejectable types though they are harder to find over land. They have never been used on commercial craft and are not considered suitable for the present application because of the excessive weight and cost penaltities involved.

The weight of typical recorders for analog data is about 20 pounds, while the digital data units are heavier. A considerable part of this is the armor plate used to protect against penetration. Generally, only the tape magazine is protected this way.

Fire protection is currently provided by either a layer of high-temperature insulation only, or insulation plus a heat sink layer which contains material that melts or vaporizes at a low temperature. Water is used for this heat sink in some designs.

High-Temperature Insulation and Heat Sinks

A great deal of work has been done in connection with the space program to develop high-temperature insulation and heat sinks for satellite reentry protection.

Most of this is not applicable to the present design problem because of differences in protection time required, maximum surface temperature, oxygen pressure, and mechanical forces applied.

Crash protection requires solving a unique problem because of the sequence of impact followed by fire. As the good thermal insulators are porous materials with low mechanical strength, they are very likely to be damaged by impact and they lose most of their insulating capability if they are crushed.

Another problem is to provide a low thermal resistance for the data storage medium during normal operation for dissipative reasons and high thermal resistance for fire protection.

Damage by penetration also tends to destroy the typically weak type of high temperature insulation.

Figure 33 shows typical conductivities for high temperature insulation from a number of sources.[31,32]

The heat transfer through the insulation is a combination radiation and conduction. The lowest conductivity achievable without evacuating the insulating space is usually the conductivity of air itself. However, a wide airspace has a much higher conductivity than this minimum because of radiation and natural convection. By subdividing the space with opaque low-conductivity partitions the convection is surpressed and radiation reduced. The latter heat transfer is roughly inversely proportional to the number of partitions in a given space.

One type of insulation, Min-K-2000, is decidely better than stagnant air.[33] This is achieved by the extremely small partition spacing. When this is reduced to a lower order or magnitude than the mean free path of the air molecules, the ordinary conduction equations break down. This insulation is very expensive and has to be moulded to required shapes. It has a low mechanical strength.

Heat sink materials should be capable of absorbing maximum heat with minimum temperature rise. The best types do this by going through a phase change. The phase change has to occur at a lower temperature than the temperature allowed for the protected space.

In spite of all the research effort expended on material properties none has been found that is as good as water. The only reason for using any other material is for lower or higher temperature protection levels.

Table 27 shows the thermal conductivity of water and some other heat sink materials for low-temperature applications taken from Reference 34 and other handbooks.

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31 ASTM STANDARDS ON THERMAL INSULATING MATERIALS, ASTM Nov. 1962

32 HEAT TRANSMISSION, W.H. McAdams. McGraw Nov. 1942

33 Bulletin from Johns Manvill Aerospace Products, 22E. North St. N.Y. 10016

34 DEVELOPMENT OF HIGH CAPACITY HEAT STORAGE MATERIALS, Cryo-Therm Inc. July 15, 1962 Inst. Lab. MIT.

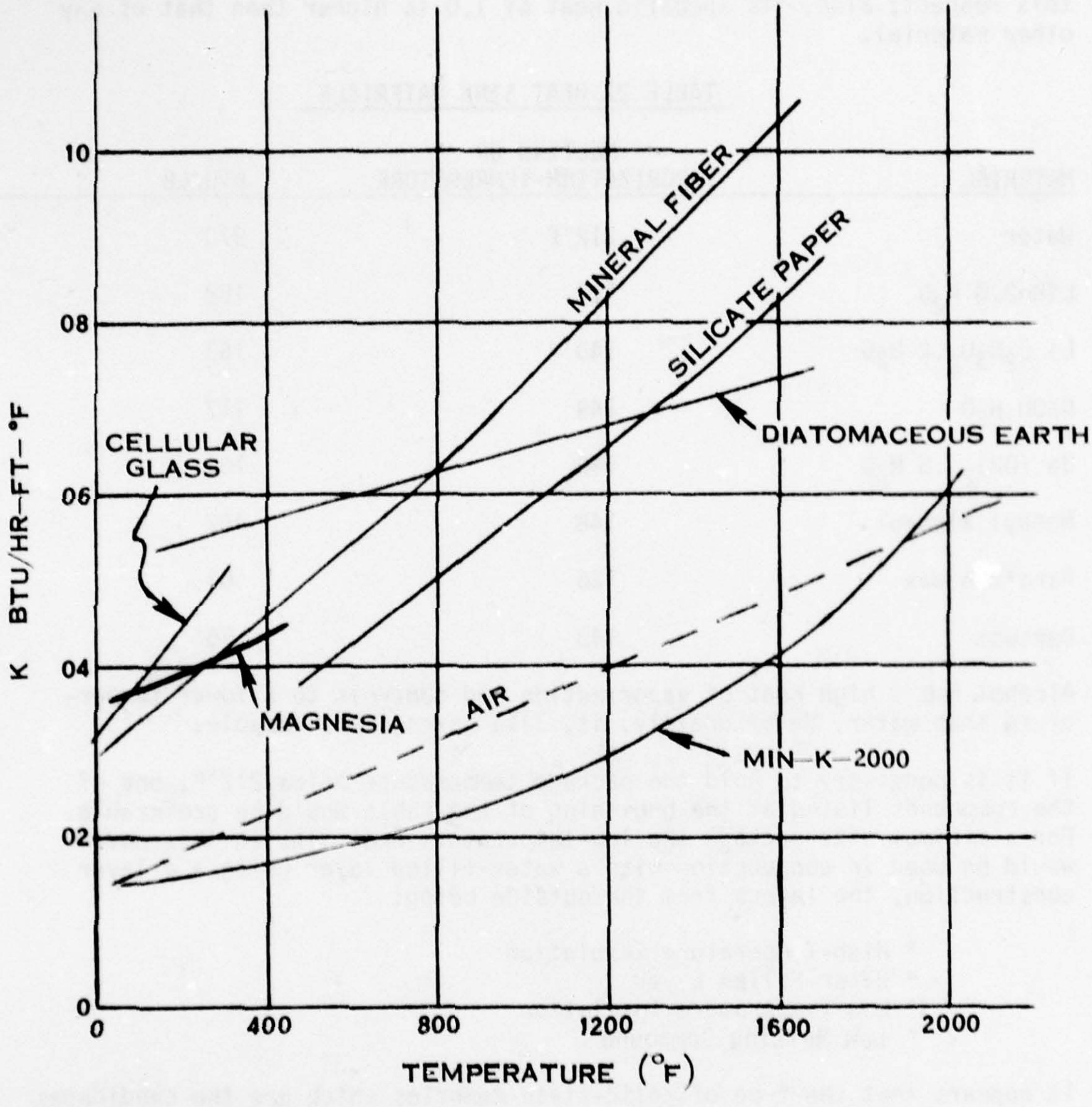


FIGURE 33. CONDUCTIVITY OF HIGH TEMPERATURE INSULATION

The specific heat of the material is also a factor since it can generally be allowed to rise about 100 degrees in temperature. Water is outstanding in this respect; also, its specific heat of 1.0 is higher than that of any other material.

TABLE 27. HEAT SINK MATERIALS

MATERIAL	MELTING OR VAPORIZATION TEMPERATURE	BTU/LB
Water	212°F	970
LiBo2.8 H_2O	122	158
Li $C_2H_3O_2$.2 H_2O	140	153
NaOH.H_2O	149	117
Ba $(OH)_2$ .8 H_2O	140	108
Methyl alcohol	148	482
Paraffin Wax	126	63
Beeswax	143	76

Alcohol has a high heat of vaporization and controls to a lower temperature than water. Unfortunately, it, like waxes, is flammable.

If it is necessary to hold the package temperature below 212°F, one of the compounds listed at the beginning of the table would be preferable. For a minimum size package the low-temperature heat sink in this case would be used in conjunction with a water-filled layer using a 4-layer construction, the layers from the outside being:

* High-Temperature Insulation
* Water-Filled Layer
* Low-Temperature Insulation
* Low Melting Compound

It appears that the type of solid-state memories which are the candidates selected for the AIRS application can tolerate 212°F, so there does not seem to be any need to use any heat sink material other than water.

Water Heat Sink

The water has to be held in a capillary matrix or gel to be useful. If it were in the form of free water any mechanical damage such as impact or penetration would allow it to leak off. Also in the presence of heat, convection currents would be generated that would degrade the insulating value. The matrix could be rigid like silica gel, but preferably it would be flexible and capable of high-temperature exposure.

Improving Survivability of Current Recorders

The FAA has conducted or sponsored a number of tests on recorders and, in addition, the National Transportation Safety Board (NTSB) has evaluated recorder operation.[26]

The FAA development effort include mechanical tests on current designs [30] and a series of fire tests. The National Aviation Facilities Experimental Center (NAFEC) conducted fire survival tests on current design of recorders[27]. This was followed by a study at Sundstrand Corporation for improved designs[28]. A final set of tests was conducted at NAFEC [29]. These reports are discussed in more detail below.

Survival Rate of Recorders

An NTSB report issued in 1975[26] summarizes the results of 503 accidents; 202 involved accidents with recorders located in wheel wells and 301 with recorders located in the tail. The change was made to improve the survival rate and appeared to be effective since only 30% as many recorders were damaged after the change.

The study included minor, as well as major, accidents. The chance of damage to a recorder is obviously greater, so the significant figure is the chance of a recorder data storage medium surviving a major accident.

This study showed that 22 recorder memories were damaged in 131 serious accidents, or approximately 17%.

In addition, 22 recorders were malfunctioning at the time of an accident. Prorated over 503 cases, this gives a probability of 4.4% of a malfunction. Malfunctions were due to either a faulty tape drive or failure to replace a full tape. The latter type of malfunction occurred with stylus engraved metal tapes that are not reusable.

The study showed that about one-third as many memories were damaged by fire as by mechanical means. This might lead to the conclusion that the fire exposure test is more realistic than the mechanical tests, or that design effort should concentrate on improved mechanical protection rather than fire protection. Since the goal for recovery after an accident is for full recovery, efforts to improve both the mechanical and the fire survivability aspects of the recorders were pursued.

Upgrading Fire Protection of Recorders

The FAA continued to seek improved fire protection. This impetus may have been due to two subsequent accidents where recorder memories were destroyed by fire, even though they were located in the tail. Another shift in emphasis resulted from the change from metal to plastic tape with lower heat tolerance.

The first of a series of tests at the Naval Aviation Facilities Experimental Center (NAFEC) in Atlantic City was in 1964.[27]

Furnace tests were run on plastic and metal tapes to determine maximum allowable temperatures. Similar tests were run on colored coatings up to temperatures of 2000°F. These were run because the specification requires that the recorder memory be painted a bright yellow or equally conspicuous color to aid in its recovery after an accident. If fire destroyed the color, the purpose of this requirement was defeated.

Five recorders of current design were subjected to high-temperature tests to destruction in a flame pit, with a standard burner, and in a furnace.

The results were:

1. Allowable tape temperatures were determined for design purposes.
2. It was found that no commonly used yellow coating could survive 2000°F or even lower temperatures. A ceramic coating was found to survive to 1750°F but even this coating peeled off the stainless-steel substrate above this temperature.
3. No current voice recorders which met the standard flame test for metal tape were capable of protecting Mylar tape under the same conditions.
4. A 1200°F furnace test was found to be equivalent to the standard 2000°F flame test and easier to standardize.

Following these tests, a study by Sundstrand Corporation was sponsored in 1969[28] to investigate improved fire protection means. This was followed by another series of tests at NAFEC in 1971[29]. These tests incorporated recommendations as a result of the above mentioned study.

The Sundstrand report analyzed the heat input to a package subjected to the standard fire test and to more rigorous ones proposed by the FAA; it also computed the survivability of different designs.

Ten packages simulating tape memories were built and tested to destruction in the second set of NAFEC tests (Figure 34).

These tests involved different constructions and three different time temperature profiles (Figure 35).

The fire protection means used in the simulated recorders included:

1. Insulation only
2. Insulation plus a thermal heat sink of paraffin wax
3. Insulation plus a thermal heat sink layer of water-filled gel.

The last type was the most successful. The wax has only one-tenth the heat capacity of water and, in addition, caught fire during the test.

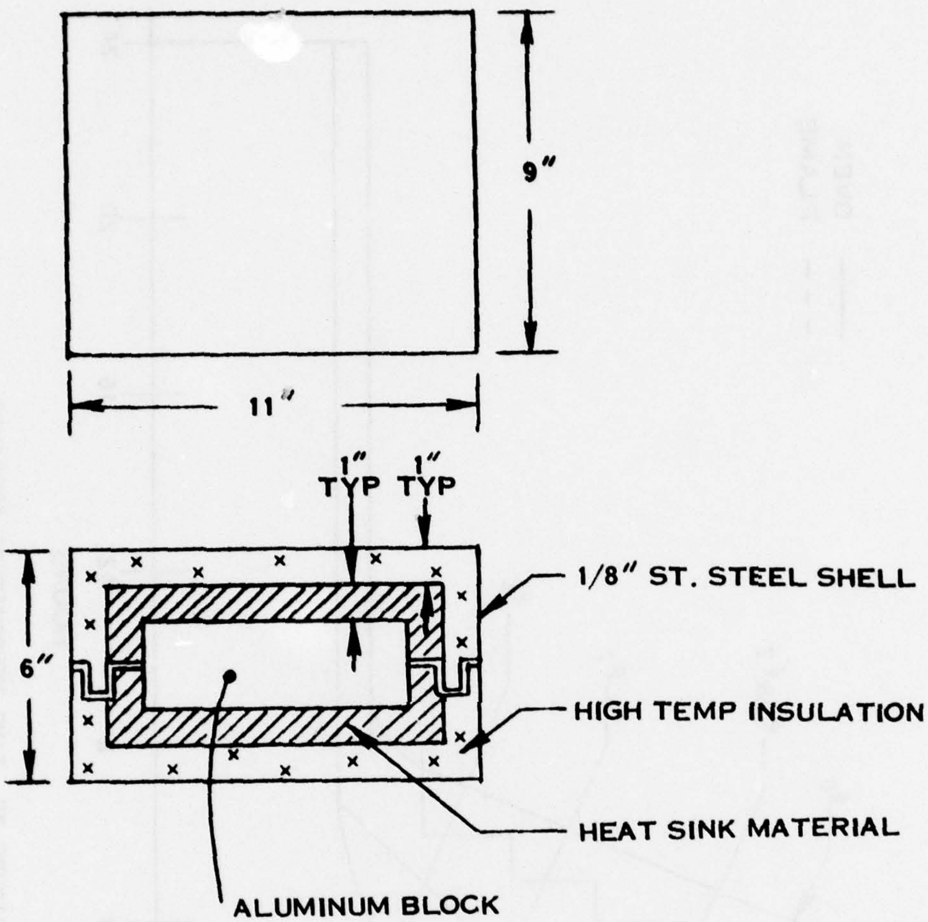


FIGURE 34. INSULATED BOXES TESTED AT NAFEC

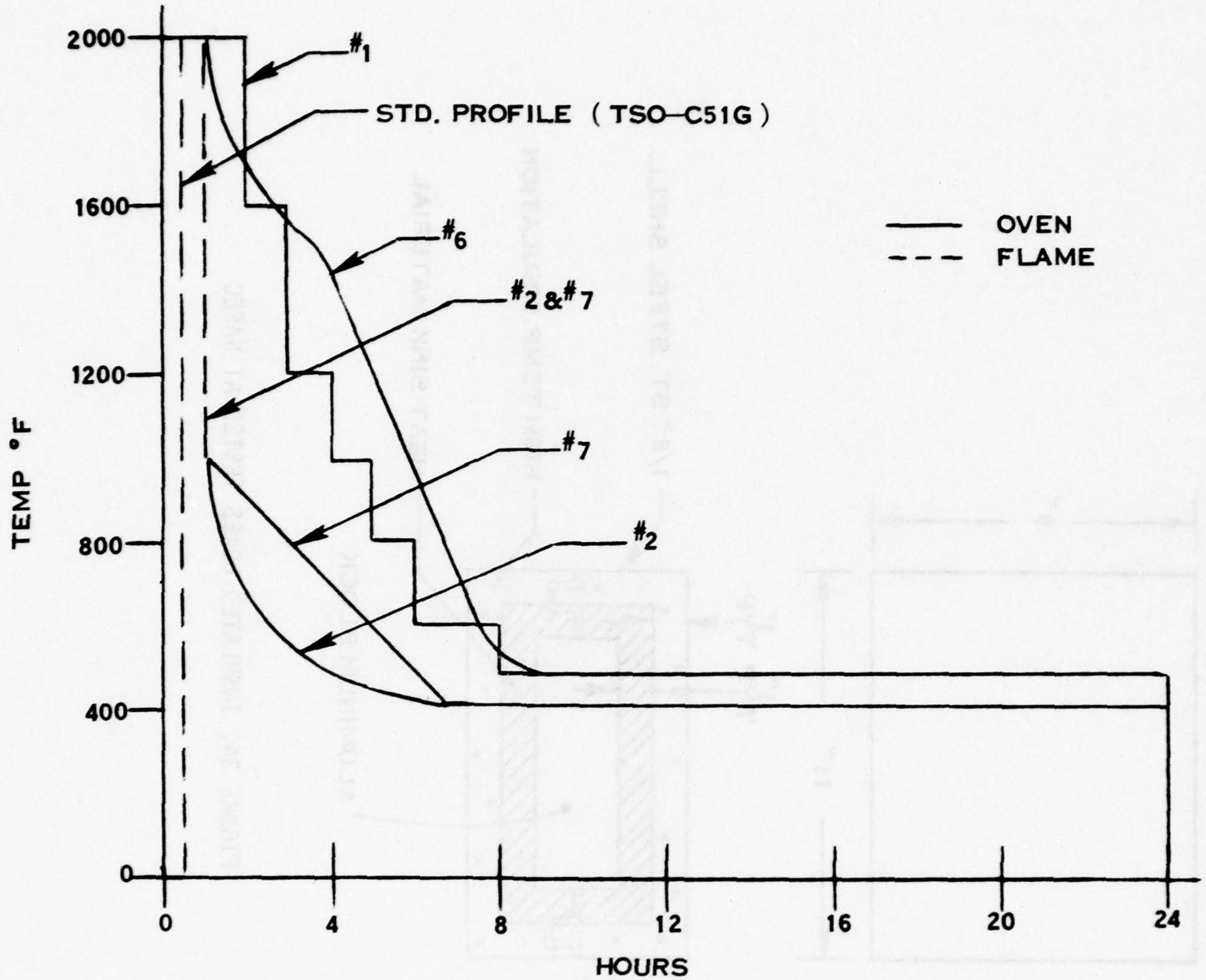


FIGURE 35. TIME-TEMPERATURE PROFILES

The most severe test profile (#1) (Figure 35) proposed by the FAA increased the initial time for 2000°F flame exposure from 1/2 hour to 2 hours and stepped the temperature down gradually over a 24-hour period to 500°F. This was intended to simulate the crash of a wide-bodied jet loaded with fuel.

This profile was never tested because the Sundstrand report concluded that it was impractical to build enough insulation into the recorder in the space available.

A modified profile (#2) was initially tested. This cut the flame exposure time to 1 hour and the heat soak 24 hours to 400°F. One recorder design passed this successfully for both Mylar and metal tape.

The profile was then increased in severity (#6), and all the designs failed to pass except for metal tape in one unit.

The 1-hour exposure at 2000°F for #6 is actually about twice as severe as for #2, the latter is done in an oven and the former with a flame at 2000°F is done in the open. The slow drop in temperature for the post-heating cycle done in an oven for #6 is also much more severe than for #2 or #7.

The final profile tested (#7) was a compromise, a little more severe than #2 but less than #6. The results with the different designs of enclosures were similar to #2. The report concluded that this last profile was a good simulation of a crash fire in a large jet.

In spite of the amount of work done on standardizing and evaluating fire tests, major questions remain unanswered regarding design values to be used.

The profiles in Figure 35 are misleading if temperatures are interpreted directly as heat input values. The important variable is heat input in Btu/hour to the protected memory. If the memory package, for example, is equivalent to a mass of aluminum of 5 pounds with a specific heat of 0.224 (Btu/lb°F), the temperature rise will be:

$$1/(5 \times 0.224) = 0.89 \text{ °F/Btu}$$

If the initial temperature is 120°F and the maximum allowable is 300°F, the maximum exposure time at a rate of 500 Btu/hr is:

$$(300-120)/(500 \times 0.89) = 0.40 \text{ hr.}$$

If the memory is surrounded by a layer containing 1 pound of water, with a heat vaporization of 970 Btu/lb., the maximum exposure time would be:

$$970/500 + 0.40 = 2.34 \text{ hrs.}$$

Some of the reports cited above mention the "Btu content" of the flame as a major variable, rather than temperature. This implies that the flame can be characterized by a single parameter, which is not true. The heat input is a complex function of all the flame parameters plus the recorded parameters.

It is important to fix a reasonably accurate value on the heat input since this completely determines the size, volume, and cost of the fire-protection means. Simplifying assumptions about the flame can give estimates of heat input that vary by a factor of 20 from more accurate calculations.

The NAFEC burner used for the flame test is described in Reference 2 as a 12-gal/hr kerosene burner that gives a flame temperature of 2000°F 4 inches from the nozzle, with an oval nozzle outlet of 4 x 8 inches. The missing parameters are:

1. Velocity of the hot gas
2. Shape of the hot gas envelope
3. Method used to measure flame temperature

Other data in the reports can be used, however, to fill in some of these gaps, and the results of the second NAFEC tests which give the pounds of water vaporized in each test can be used to check the total heat input.

Heat Balance During the Flame Test

Figure 36 shows the complicated heat transfer in this test. The major heat input to the surface of the box is convection and radiation from the flame, qc_1 and qr_2.

Heat loss from the major surface is by radiation, qr_1, and conduction, qk_1 and qk_3.

The test specifies that "at least half" of the surface of the box be enveloped by flame. In practice the major surface is tilted at about 30 degrees to the flame and the nearest corner is about four inches from the nozzle. Although only half the total surface is facing the flame, the back side of the box will be in contact with hot gas at practically the same temperature, since it is impossible to shield it under the test conditions specified. For this reason the heat balance will be made on the assumption that the whole surface of the box is subject to convection from a gas at temperature Tg. The temperature of front and back surfaces T_{s1}, and T_{s2} will be assumed equal to T_s, and conduction between the two (qk_3) will then be zero.

Heat from the surface will be conducted through the insulation by conduction (qk_1 and qk_2) to the protected package at temperature T_0; qk_1 being assumed equal to qk_2 since T_{s1} is assumed equal to T_{s2} and total heat conducted into the package will be equated to qk.

The gas temperature Tg is specified as 1100°C or 2000°F. This was measured by a thermocouple 4 inches from the nozzle. A simple unshielded thermocouple under these conditions will have a radiation error from 100° to 500°F. Assuming a 200-degree error, the actual temperature is probably about 2200°F. There will be mixing with cooler air as the flame sweeps around the box, however, and since a uniform temperature is assumed, it is probably a good approximation to assume an average gas temperature of 2000°F over the whole box.

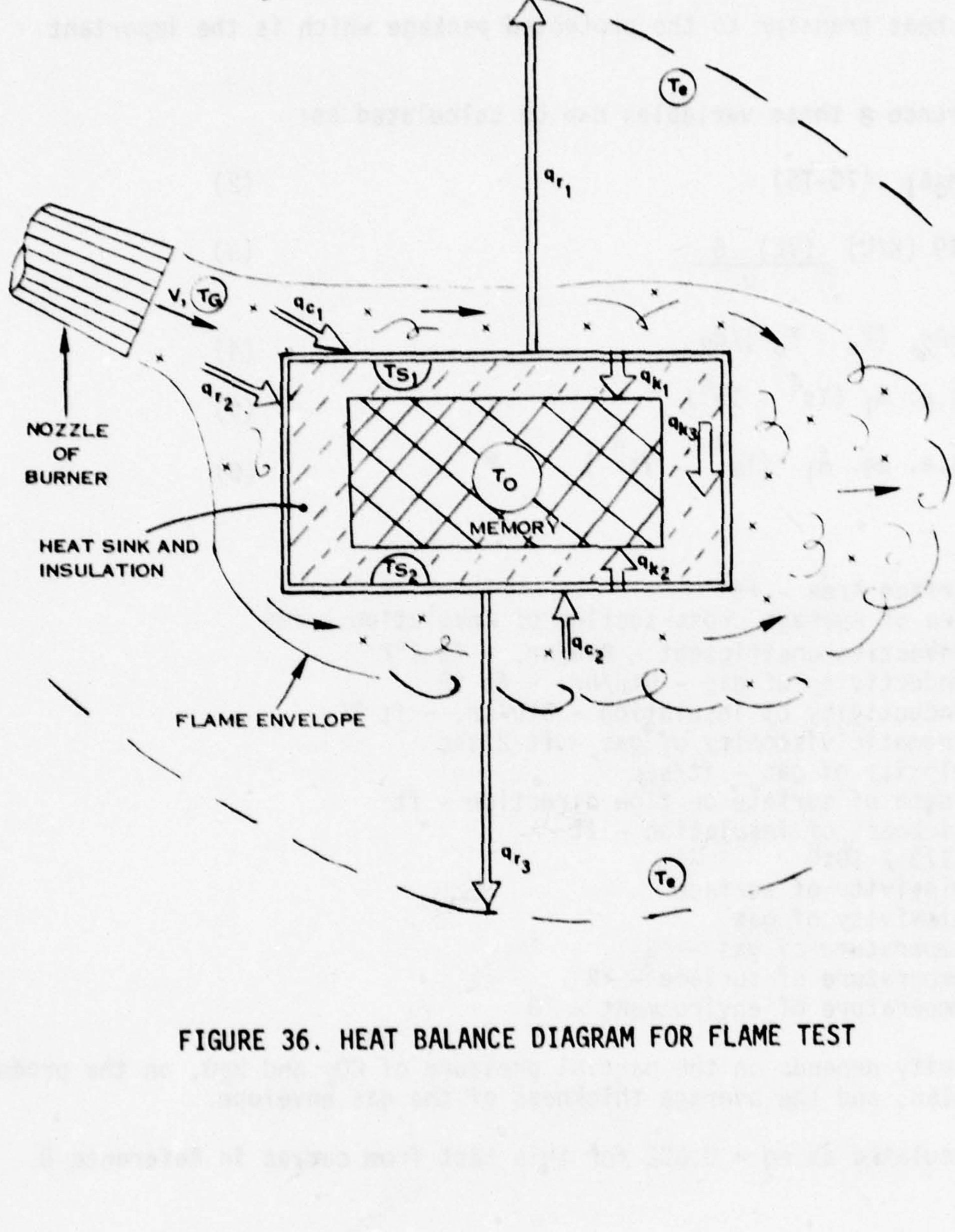


FIGURE 36. HEAT BALANCE DIAGRAM FOR FLAME TEST

The heat balance is:

$$qk = qc_1 + qr_2 - qr_1 \qquad (1)$$

qk is the heat transfer to the protected package which is the important variable.

From Reference 8 these variables can be calculated as:

$$qc = h_c A_1 \quad (TG-TS) \qquad (2)$$

$$hc = .49\ (K/L)\ \frac{(VL)\ .5}{u} \qquad (3)$$

$$qk = K_2 A_2 \quad (T_s - T_o)/d_2 \qquad (4)$$

$$qr_1 = s.e.\ A_1\ (Ts^4 - Te^4) \qquad (5)$$

$$qr_2 = s.e.\ eg.\ A_1 \quad (Tg^4 - Ts^4) \qquad (6)$$

Where:

A_1: Surface Area - ft^2
A_2: Area of average cross-section of insulation - ft^2
h_c: Convective coefficient - Btu/hr. - ft 2°F
K : Conductivity of gas - Btu/hr. - ft °F
K_2: Conductivity of insulation - Btu/hr. - ft °F
u : Kinematic viscosity of gas - ft 2/sec
V : Velocity of gas - ft/sec
L : Length of surface on flow direction - ft
d_2: Thickness of insulation - ft
S : 0.173×10^{-8}
e : Emissivity of surface
eg: Emissivity of gas
Tg: Temperature of gas - °R
Ts: Temperature of surface - °R
Te: Temperature of environment - °R

Gas emissivity depends on the partial pressure of CO_2 and H_2O, on the products of combustion, and the average thickness of the gas envelope.

It was calculated as eg = 0.052 for this test from curves in Reference 8.

Luminosity of the flame was ignored because Reference 8 recommends this for hydrocarbon fuels. Even though these flames are luminous in the visible spectrum, this adds little to their total radiation.

Solving all these equations to determine qk in EQ. 4 is fairly laborious, since it involves fourth-order equations that have to be solved empirically. The solution consists of evaluating the surface temperature T_s first, and then substituting this in Eq. 4 to get qk.

The results give steady-state equilibrium values after initiation of the test. However, transient temperatures can be evaluated from these values by knowing the heat storage capacity of the box and insulation. This is considered below.

Emissivity of the surface has an important effect on its temperature. If it is a black surface with an emissivity of 1.0, it will absorb the maximum amount from the gas, but also radiate the maximum amount to the environment. If these were the only two modes of heat input and output, the temperature would be the same for any value of (e) but, since a large part of the heat input is convective, the high-emissivity surface (blackened) will remain cooler than a low emissivity one (such as a polished metal).

Figure 37 shows calculated surface temperatures of varying emissivity for a typical box as shown in Figure 34 . This shows that the surface temperature is always below gas temperature for an emissivity greater than zero. When e = 0 there is no radiation in or out of the box, so the convective heat transfer raises the temperature to Tg.

In the Sundstrand report,[29] it is stated that a low emissivity is desirable to limit the heat input. No calculations of surface temperature are shown, and it is assumed that emissivity of the flame is 1.0, giving about 20 times as much direct heat input as the calculation above. This conclusion has some validity when transient conditions are considered. Although a low-emissivity surface will have a higher equilibrium temperature than a high-emissivity one, it will heat up to this temperature at a slower rate. Time constants have been calculated for typical boxes, and they average about 8 minutes. Since this is a small part of the flame exposure time, the equilibrium conditions are more important than transients, so the conclusion that high-emissivity surfaces will limit total heat input more than low-emissivity ones seems valid.

The high flame emissivity assumed by the Sundstrand report is inconsistent with the experimental results in Reference 4.

Surface temperature below 1000°F as shown in Figure 37 might seem inconsistent with results reported in the NAFEC tests where aluminum boxes melted. This requires about 1100°F temperature. However, aluminum has a basically low emissivity, ranging from 0.04 to 0.08 from 0 to 1000°F. Since the paint coatings were observed to burn off almost immediately, this would expose the bare metal to the flame. An emissivity less than 0.15 would allow the aluminum to reach melting temperature.

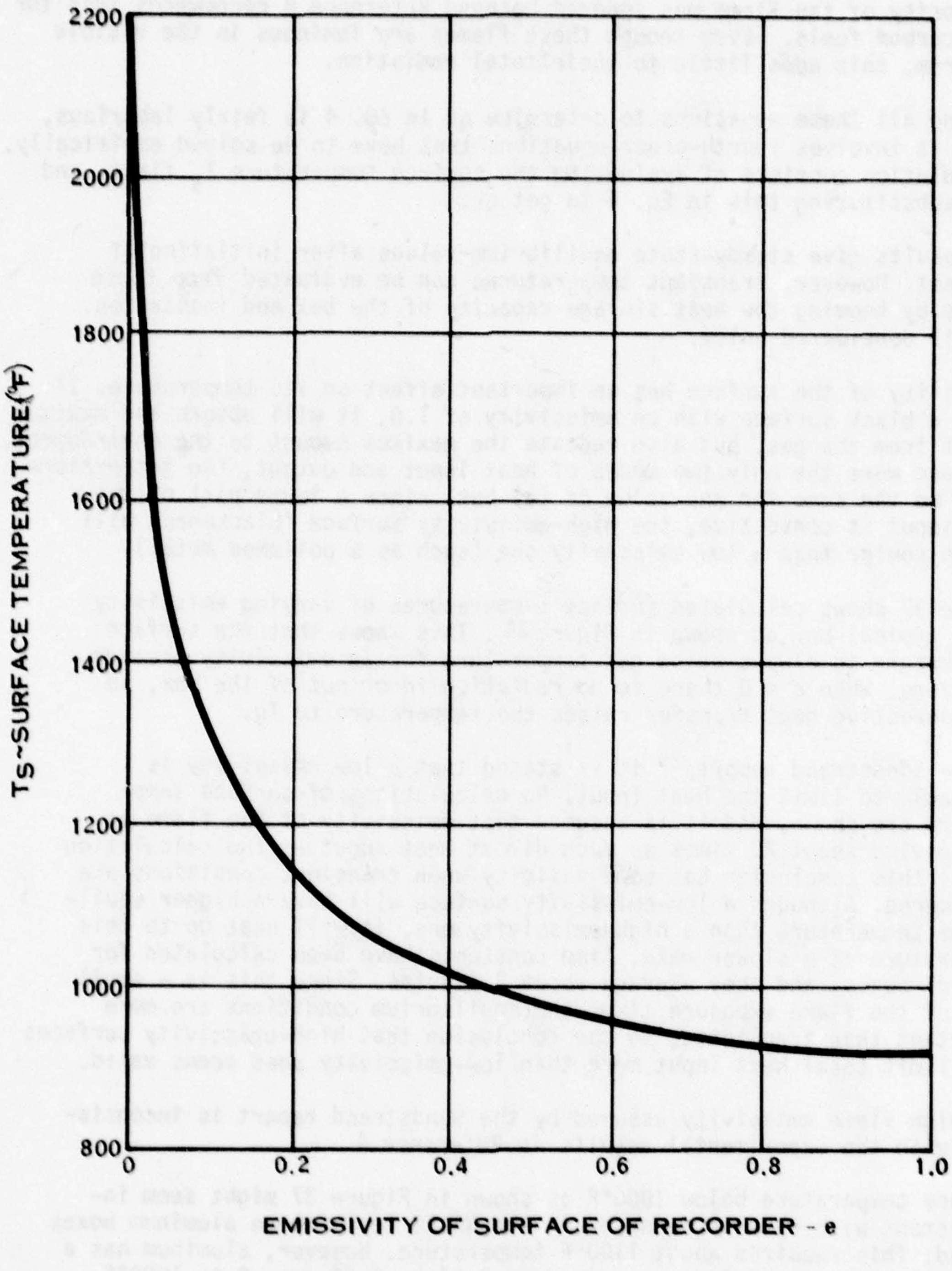


FIGURE 37. TS VS e FOR GAS TEMPERATURE OF 2200°F NAFEC STANDARD FLAME

One of the missing variables in the definition of the NAFEC flame is velocity of the hot gas, and this is necessary to solve Eq. 3 for convective heat input.

These check within 7%, which is very close considering all the approximations that were made. This lends confidence to the use of the equations in predicting survivability of a new design.

Mechanical Test on Recorders

The impact test requires an elaborate test setup, since it specifies a 5-millisecond shock pulse of 1000 g. The length of the pulse is a measure of the energy input and is also critical in determining amplification effects due to resonance. The maximum amplification for a 0.005-second pulse would be at a natural frequency of:

$$1/(2 \times 0.005) = 100 \text{ Hz}$$

To visualize the sort of impact specified: If the pulse shape is assumed rectangular (constant acceleration for 0.005 second), this gives a displacement during this time of 0.4ft. The initial velocity required is 160 ft/sec. Thus, this pulse would be generated by a body dropping from an altitude of 400 ft and penetrating 0.4 ft into a substance like sand.

This obviously is a good approximation of crash conditions but it requires test facilities of a special sort.

The tests were conducted at two different facilities. In one case, an air cannon 90 feet long was used, and the pulse was applied by accelerating the package. In the other case, an hydraulically driven sled on a 40-foot track was used, and the pulse was generated on impact with a crushable honeycomb.

Each type of recorder survived on the two short axes and failed on the long axis. The mechanical collapse destroyed the tape memories in each case. It was concluded that one would have to be completely redesigned to meet the specifications, and the other required major modifications.

The solid-state memories proposed for the present application are inherently much stronger than tape memories. The basic chips, such as the MNOS memories are made of, have been tested in flatpack enclosures up to 20,000 g in centrifuges. Their natural frequencies are much higher than 100 Hz, so no resonance effects are expected in a test like this. For these reasons the impact test is not considered a crucial one.

Static Crush Test

This is a simple test to design for since it only involves static forces. The recorders tested in the NAFEC program passed this with no problems. A package designed to survive the penetration test below is almost certainly strong enough to pass this one.

There is one aspect of this test which does not seem to have been evaluated in the NAFEC tests, this is the static crush followed by fire. If the insulation is crushed it will be less effective in protecting against fire. However, it could be argued that, in an accident that resulted in this kind of static crush, the recorder would have to be located under a main structural member of considerable size and, in this position, it is unlikely to be exposed to fire.

Penetration Test

In Reference 30 there is a complete description of the test as run at NAFEC. This test is supposed to simulate a bolt or some other small structural member striking the recorder during a crash.

It was found in trying to run this test that the length and strength of the penetrating member of 0.05 in^2 was critical and not defined. If a long bolt is used, it buckles at a low stress level and fails to penetrate. A 1-1/2-inch length was chosen as the longest practical. The tensile strength required was found to be 200,000 pounds per square inch since a softer bolt would bend, and stronger materials tend to fail in brittle shear. Even picking the maximum strength member for this test does not mean that it will not fail at some force level. In fact, if the package is protected adequately, the penetrating member has to fail before the armor fails, so the strength of this member really determines the strength of armor required.

The method of supporting the recorder was not specified. If it is rigidly supported by a heavy mass it will tend to develop more force on impact but will not accelerate appreciably. In this case, it will also be subject to crushing by the 500-pound weight if the penetrating member fails, and this is not intended to occur. If it is more softly supported, the impact of the spike can cause an acceleration that greatly exceeds the value called out in the impact test above.

The method agreed on for the tests in Reference 30 was to support the box on fine sand. It was driven into the sand by the impact but was not crushed by the 500-pound weight.

This test condition requires some sort of armor plating to protect the memory. There is a considerable amount of technology available to evaluate armor plate to resist projectiles or meterorites for space applications. However, these high velocities impose stresses that are basically different from this penetration test. The velocity in this case is low, about 25 ft/sec, and the stresses can be treated as static. In the case of hypervelocity impacts the velocity is higher than the velocity of sound in the material (about 16,000 ft/sec for steel), so all the energy is concentrated in a small volume, resulting in instantaneous vaporization of the metal. At low velocities the energy is spread out by elastic waves over a larger volume.

There is an approximation in using static stress values for a short impact since metals show higher strength for short stress cycles than long ones. However, this strengthening will affect both the armor and the penetrating member, so it is felt that this is a negligible error.

In the NAFEC tests both types of recorders survived this penetration test. The spike penetrated an outer steel skin but did not damage the tape memory. Since the recorders were quite bulky, it is not clear whether the 1-1/2-inch spike was long enough to reach the memory, since the weight would tend to press on the outside of the case and drive the whole recorder into the sand, and the outer case did not appear to be crushed to any extent.

Design Objectives for Crash Protection

The major design problems to meet the FAA test requirements are fire resistance and penetration resistance. A design that will meet the latter test is almost certainly strong enough to meet the static crush and impact tests.

Secondary objectives are means of recovering the memory after a crash and design of the main electronics package to survive a 150 g impact for 10 milliseconds.

Mechanical Protection

The maximum force of penetration exerted on an area of 0.05 in^2 by a steel bolt as described above is the force that such a bolt can stand without being crushed. This was evaluated from the equations in Reference 36 as being 7300 pounds. Armor plating can be designed to resist this load applied over a circle of 0.05 square inch from the equations in Reference 35.

Fire Protection

Although the NAFEC report [29] concludes that profile #7 in Figure 34 is a good simulation of a crash fire with a large jet, it does not follow that this is a good model for a typical helicopter fire. The cooling time factors applicable to a large jet should particularly be evaluated for the helicopter.

Starting with equal initial temperatures, the cooling rate of a wreck should depend on the gross weight, since weight represents heat content and weight varies as ($W=L^3$). Where L is a typical dimension and surface area varies as ($A=L^2$), cooling time should vary as ($W/A = L = W^{1/3}$). Taking a typical helicopter weight as 20,000 pounds and a large jet as 300,000 pounds the cooling time should be $\left(\frac{2}{30}\right)^{.333} = 0.40$ times as long for the helicopter.

If each carries the same percentage of fuel-to-gross weight, the combustion time for the fuel should follow a similar law since the rate of burning is proportional to surface area and the total amount to volume. If one hour of burning is typical for the large jet, the smaller should only burn for 0.40 hour, which is close to the FAA specification of 0.5 hour.

It is felt that a reasonable fire-protection requirement for this application is a 2000°F flame test of one hour. Of this, 0.4 hour would represent the actual fire and 0.6 hour the cool-down period. It might seem over conservative to allow more heat input to the box after the fire is out than during the fire in view of the fact that survival records of recorders are reasonably good even though they are only tested for 0.5 hour of flame exposure with no post heating. However, most of this represented results with metal tape recorders. Once the fire is out, the temperature would tend to drop almost immediately to about 1000°F, which is an allowable temperature for the metal tapes; thus these recorders were not required to survive the long cool down that a plastic tape must stand. If plastic tape or electronic/magnetic memory devices are to be considered as an AIRS data storage media then the added fire protection appears necessary.

Recovery of the AIRS Unit and/or the Memory Module

The FAA specification requires the recorders to be painted a bright yellow or equally high visibility color to aid in recovery. The results of the tests in Reference 27 show, however, that few yellow coatings can be expected to survive a fire, and even if they do it is unlikely that they would not be blackened by soot. However, since approximately 95% of major incidences are expected not to involve fires, a bright paint coating still appears useful. For an incident involving fire, the AIRS unit could be burned away, leaving only the thermally protected memory module. Under these conditions, the memory module may be difficult to locate at the wreckage site. To aid in the location of the module, at least two methods of enhancing location are suggested.

1. Magnetic detectors might be used effectively for cases when the memory is separated from the general mass of wreckage. The armored case might be deliberately magnetized to allow magnetometers to be used in locating it.

2. Radioactive means would appear to be feasible for location. If a low-energy radioactive material is placed in the memory enclosure, it could be located with a Geiger counter. These are sensitive enough so that the energy output could be well below the maximum allowable for crew exposure.

Survival of Main Electronics Package

An additional trade-off consideration for this application is the ability to record information for five seconds after impact, where any impact does not exceed 150 g's for 10 milliseconds.

AIRS Package Physical Design Considerations

At least two general methods of memory module protection are possible for the combined mechanical and fire environment:

1. Fire protection inside an armor-plated package.
2. An armor plate contained inside the fire protection.

The second method appears to be the most desirable in limiting total weight since the fire protection is bulky, and anything that increases the volume enclosed by the armor adds significantly to total weight. The weight of armor increases by a factor greater than total the surface area since it takes thicker armor to give the same protection to a large surface than to a small one. However, if the armor is inside the fire protection, an outer shell is still needed to contain the entire module. It could be advantageous therefore to provide contaminent and armoring in one enclosure.

Design of the Memory Module for Mechanical Protection

As previously stated, a successful design to resist penetration will automatically result in a module that will resist the shock and crushing loads as given in TSO C51a. Three shapes of armor-plated enclosures are shown in Figure 38. All are evaluated for a memory in a flat-pack configuration (2 inches square by 1/4 inch thick).

The spherical and cylindrical packages have poor space factors for this shape of memory. For other shapes they might be more suitable. They are basically stronger so they can use thinner walls than the rectangular package. Stresses and necessary wall thickness of the different geometries are evaluated from the results of Section 4.8 and equations taken from References 35 and 36.

Relative surface area, volume, and weight are shown in Table 28.

TABLE 28. DESIGN OF THE MEMORY MODULE FOR MECHANICAL PROTECTION

Type	Wt.	Surf. Area	Volume
Spherical	0.96 lb	21.2 in^2	9.2 in^3
Cylindrical	1.46 lb	28.3 in^2	13.2 in^3
Rectangular	1.55 lb	26.9 in^2	7.8 in^3

The sphere has the lowest weight and surface area but a larger volume than the rectangular, thus cooling the contents by conduction is more difficult. It is probably the most expensive construction.

A cylindrical package is probably about as inexpensive to build as the rectangular package since it is mostly lathe turning. It has a stronger enclosure than the sphere. It does not appear attractive in terms of the parameters listed in Table 29 for this application.

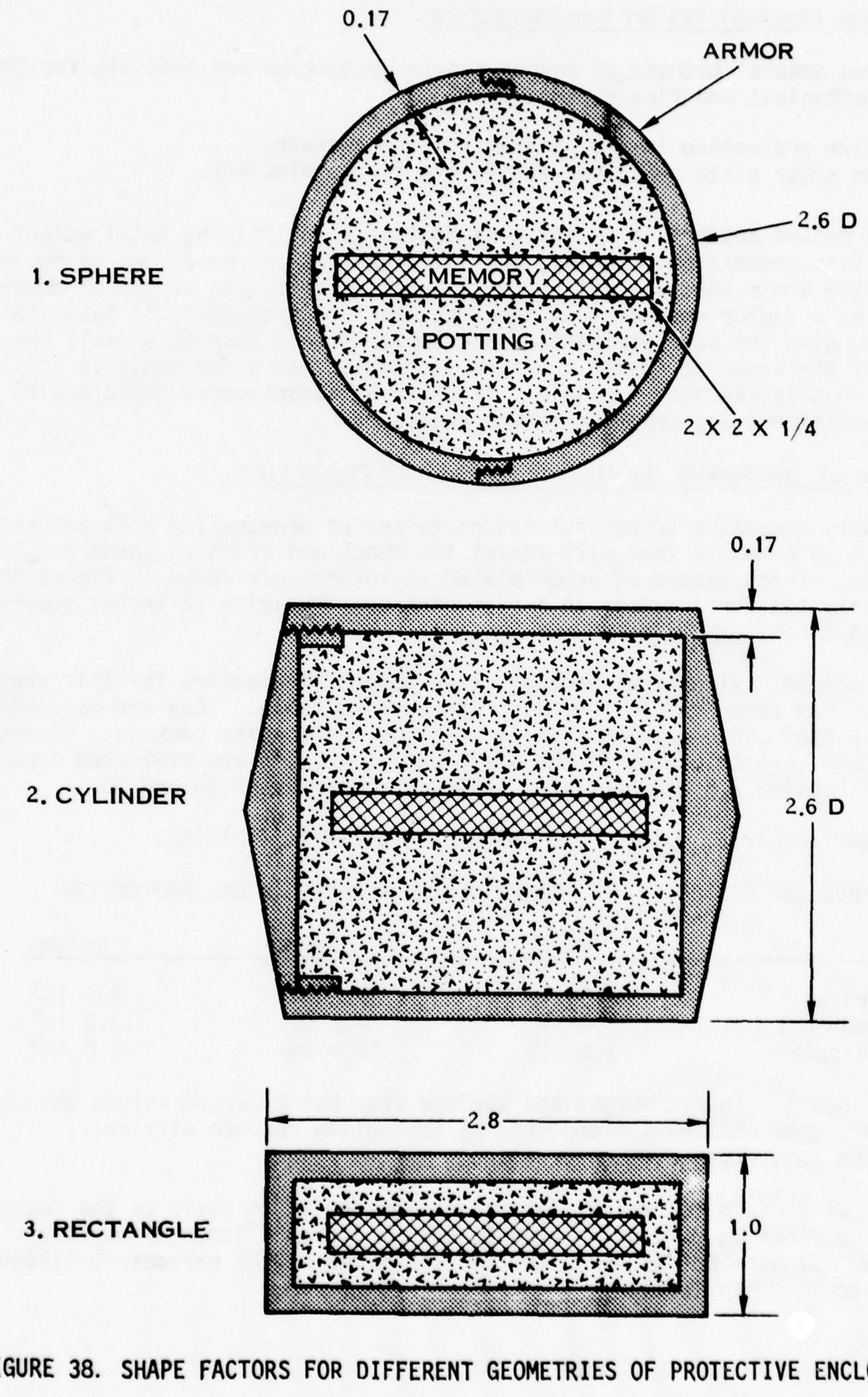


FIGURE 38. SHAPE FACTORS FOR DIFFERENT GEOMETRIES OF PROTECTIVE ENCLOSURES

TABLE 29. DESIGN OF MEMORY PACKAGE FOR FIRE PROTECTION

Total heat storage capacity: (Btu)	
Water Heat Sink:	3186
Shell:	2072
Insulation:	600
Contents:	60
	5918
Total heat input:	
1-hour flame exposure	1564
23 hours post heating	4760
	6324

The enclosures could be fabricated from any of a number of tool steels that can be heat-treated to better than 200,000 psi tensile strength. The rectangular package might be welded from plate stock.

Because of its convenience for packaging, the rectangular shape is probably the best for this shape of memory in spite of slightly higher weight and surface area than the sphere.

Lead wires would be of minimum size to limit heat leakage into the package in a fire. They would not have to be hermetically sealed to the armor plate enclosure. The memory itself would be hermetically sealed and would be resistent to sea water penetration.

Mechanical Design of Electronics Package

The main electronic package would contain the thermally protected memory module and other non-protected subassemblies. It would use conventional circuitry on multi-layer printed circuit boards with the possibility of design features to take the 150 g shock loads.

The printed circuit boards would be small enough to take shock loads of many times 150 g. They would be rigidly supported and securely held in metal frames. Interconnections would be made by a master interconnect board soldered to the PC boards or with bolted connectors to guard against the chance of connectors coming loose during the impact.

The overall AIRS unit would be solidly attached to a frame member of the aircraft for maximum survivability in a 150 g crash. At this level of impact the main frame would be expected to remain essentially, intact.

From a mechanical point-of-view the additional weight and complexity to survive a 150 g ten millisecond shock load in any axis as compared to normal Mil packaging requirements (15 g's for 15 milliseconds) is not expected to significantly increase size, weight and complexity. The major impact is one of unit repairability. Typical Mil-spec design would allow connectors between PC cards and modules and quick-locking module supports. These features would obviously increase repairability compared to a more rigid bolted assembly. However, since the inherent MTBF of the unit is expected to be greater than 10,000 hours, the increased cost of maintainability is also considered to be negligible.

Design of Memory Package for Fire Protection

From the record of survivability of present recorders and the tests reported in Reference 30, the most reliable protection is a good heat sink combined with insulation. A general design on this basis is decribed in further paragraphs of this section as an additional means of insulating the package.

Basic Design for Fire Protection

As discussed previously, it is necessary to design a high-temperature insulation that will not be damaged by impact and one that will not interfere with cooling during normal operation.

A construction method that solves both these problems and makes best use of the space available uses a water-soaked wick of high-temperature insulating material like mineral fiber. This has the following advantages:

1. A high level of fire protection for a given volume
2. High impact resistance
3. Low internal thermal resistance in normal use

The space between the memory and the outer wall can be filled with water-soaked material. As the outer part of the wick dries out it becomes an efficient insulator to protect the inner part from the heat. This protection gets progressively better as the heating period increases. To keep the wick from evaporating in normal use and to ensure that it will dry out systematically from outside to inside, it is necessary to enclose it in a waterproof container. A further refinement would be a multi-layer consisting of layers assembled inside each other, each consisting of a wick enclosed in a sealed plastic bag. This is shown in Figure 39. The bags would have blow-out plugs to vent the steam automatically.

Assuming each layer is 1/8 inch thick and is 80% water, a calculation was made of the fire protection afforded to a small memory exposed to the standard FAA flame test. Survivable time is listed for one to four layers in Table 30.

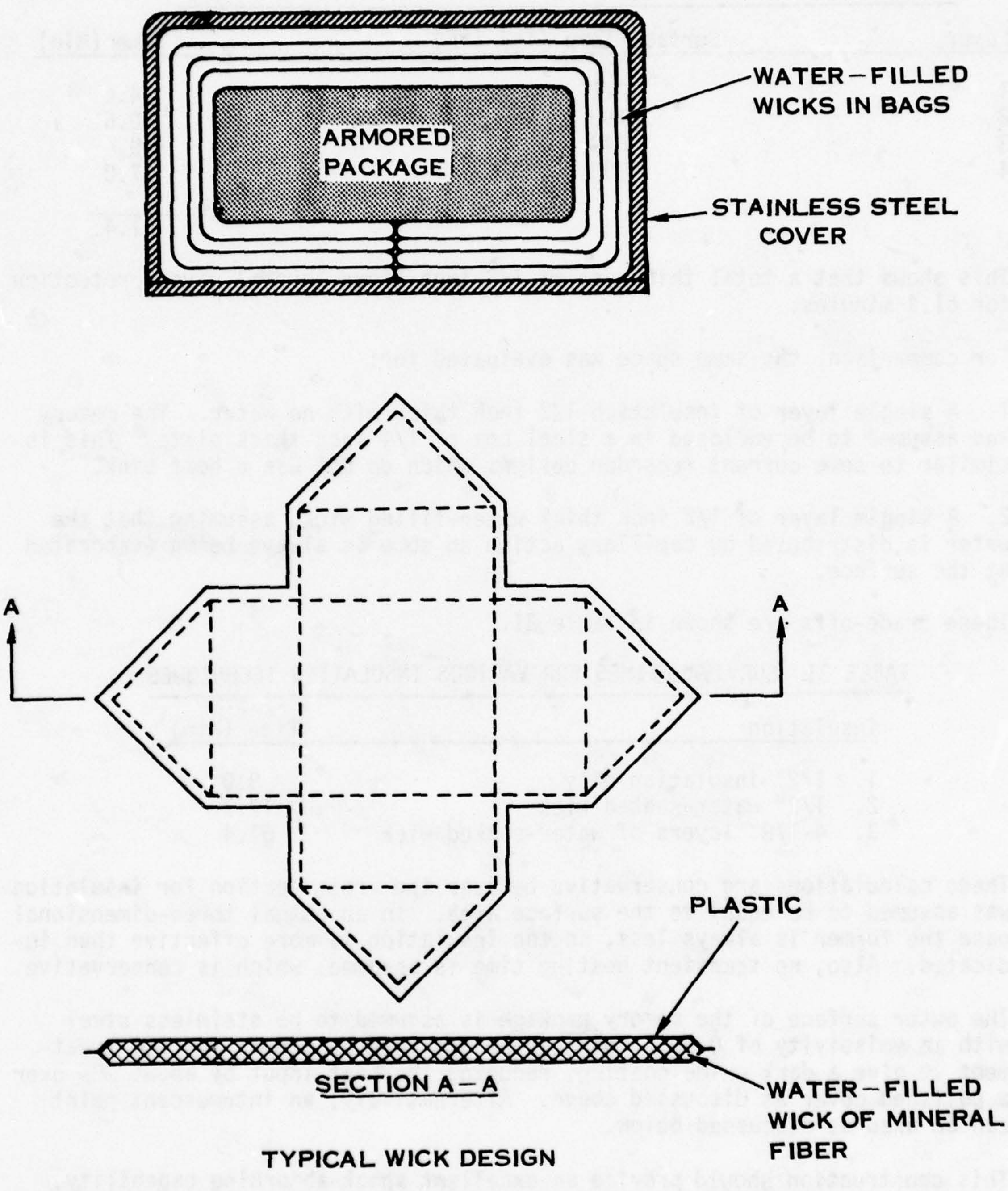


FIGURE 39. FIRE-RESISTANT CONSTRUCTION FOR MEMORY

TABLE 30. SURVIVAL TIME VERSUS NUMBER OF INSULATING LAYERS

Layer	Surface Temp (T_S) (°F)	Time (Min)
1	212	4.4
2	790	10.6
3	840	19.4
4	890	27.0
		61.4

This shows that a total thickness of 1/2 inch (four layers) gives protection for 61.4 minutes.

For comparison, the same space was evaluated for:

1. A single layer of insulation 1/2 inch thick with no water. The memory was assumed to be enclosed in a steel box of 1/4 inch thick plate. This is similar to some current recorder designs which do not use a heat sink.

2. A single layer of 1/2 inch thick water-filled wick, assuming that the water is distributed by capillary action so some is always being evaporated at the surface.

These trade-offs are shown in Table 31.

TABLE 31. SURVIVAL TIMES FOR VARIOUS INSULATING TECHNIQUES

Insulation	Time (Min)
1. 1/2" insulation only	8.0
2. 1/2" water-soaked wick	17.7
3. 4-1/8" layers of water-soaked wick	61.4

These calculations are conservative because the cross-section for insulation was assumed to be equal to the surface area. In an actual three-dimensional case the former is always less, so the insulation is more effective than indicated. Also, no transient heating time is assumed, which is conservative.

The outer surface of the memory package is assumed to be stainless steel with an emissivity of 0.90. This can be provided by proper surface treatment to give a dark oxide coating, reducing the heat input by about 30% over a polished cover as discussed above. Alternatively, an intumescent paint can be used as discussed below.

This construction should provide an excellent shock-absorbing capability. The water is practically incompressible and, being confined in capillary passages, cannot move appreciably during the short impact even if the cover is ruptured. The cover would be a tough stainless steel enclosure that resists tearing.

One of the main advantages is that the porous structure will not be crushed, so it can function efficiently as a heat insulator after drying out.

During normal operation it is necessary to conduct electrical heat out of the memory. Water has a relatively high thermal conductivity, and calculations show that the temperature drop through the insulation for 1/2 inch thickness is typically less than 2°F for the heat loads imposed by typical solid state memories. The protection layer changes in thermal conductivity by a factor of about 10 when it dries out, so this construction solves the problem of variable thermal conductivity for the operating and crash modes.

At ambient temperatures below 32°F the water would freeze, but this does not interfere with its use as a heat sink and shock-absorber. The only precaution necessary is to allow enough room in the package for expansion when the freezing occurs. It is obviously a better heat sink when frozen than it is when liquid.

Additional Fire Protection by the Use of Intumescent Coatings

An intumescent coating on the outside of the basic package itself and the non-mating surfaces of the enclosed memory module would afford still more fire protection. This material bubbles and chars in the presence of heat. It is well suited to this application since it combines impact resistance with high-temperature insulation. It adds a factor of safety to the insulation described above for cases of penetration damage.

One weakness of the protection described above and for all current recorders is the chance of an accident that involves penetration which destroys a large part of the thermal insulation. An intumescent coating can be self-healing under these conditions since some types expand to 150 times their original volume and tend to spread over the whole surface.

One possible type of coating would be a silicone-base material, having the consistency of rubber at room temperature, which would become plastic at 100°C. If this were impregnated with a blowing agent such as used in commercial foam production it would bubble at a preselected temperature like 110°C. Another possible type is a pyrotechnic coating that burns spontaneously when ignited and leaves a foam residue of carbonaceous material.

Mechanical Design Trade-Off Data - Memory Module

Preliminary estimates of weights and volumes for a number of different memory module designs as determined in phase I are listed in Table 32.

The importance of the trade-off data presented here is primarily in the relative values of size and weight of the various memory module configurations.

In phase II the fully protected memory module was further examined for the recommended configuration A and found to weigh approximately 2.5 pounds and have a volume of 20 cubic inches.

TABLE 32. SAMPLE OF MEMORY MODULE DESIGNS

MEMORIES	Full Protection		Armor Only		No Protection	
	Wt. (lbs.)	Vol. (cu. in)	Wt.	Vol.	Wt.	Vol.
A. 32K MNOS	2.82	25.4	1.17	4.84	.05	.47
B. 128K MNOS	4.38	38.7	2.13	9.25	.22	1.87
C. 100K Bubble-Without elec.	2.52	22.1	.96	3.96	.14	1.17
D. 100K Bubble-With elec.	4.20	35.6	1.96	8.75	.43	3.6
E. 500K Bubble-Without	4.20	35.6	2.46	9.0	.47	3.9
F. 500K Bubble-With	7.86	64.8	4.41	21.8	1.41	11.76

5.0 CANDIDATE SYSTEM ANALYSIS AND CONCEPT SELECTION

The systems that are considered as possible candidates for the Accident Information Data Retrieval System function span a broad range from existing electromechanical recording systems to systems that use some of the more recent developments in digital solid-state technology.

The candidate systems can be divided into two major categories: those using a mechanical recording device and those using a solid-state memory. Candidate systems can also be divided by their major function as data recording only, audio only, or data and audio combined. Candidate systems are first identified and discussed in each of six combinations of memory technology. The most promising major category is then further divided into more specifically defined candidate systems.

In each case the system is described, the advantages and disadvantages are discussed, and the justification for retaining or discarding a candidate system is clearly stated.

5.1 MAJOR SYSTEM CLASSIFICATION

Mechanical Recording Systems

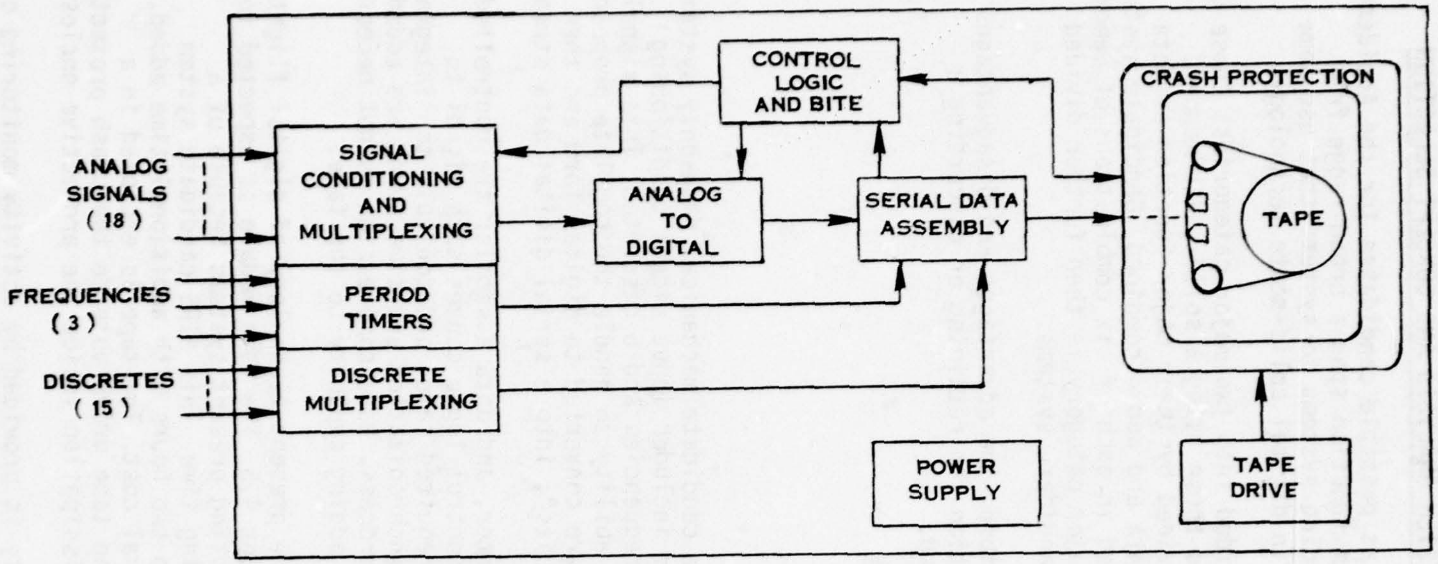
Mechanical Data System

A functional block diagram of the candidate mechanical data-only system is shown in Figure 40. The system includes input signal conditioning for up to 18 analog signals, 3 frequencies and 6 discretes. This signal capability gives this system the ability to handle the complete proposed signal list. The analog signals are converted to digital form and then assembled, along with discrete "bits", into a serial digital data stream.

The data multiplexers, A/D converter, and data assembler are controlled by a control logic section. The control logic causes each signal to be sampled and converted at the required rate, and controls the integration of the data into a data frame. Synchronization and time words are added to facilitate the data recovery process. Data compression is not necessary because of the low delta cost of adding capacity to the tape.

The tape mechanism is based on the present technology of digital flight data recorders discussed in Section 4.5. The tape module is expected to be somewhat smaller than the existing present systems because of a reduction in the required recording time. This AIRS candidate system could be expected to record up to two hours with additional time added, if necessary, for little additional cost. The tape is enclosed in a crash-protected enclosure with the tape drive outside the crash protection to minimize the size and power dissipation inside the protective enclosure.

A limited built-in test capability is provided by activity monitoring of data recorded on tape via a read-after-write head and monitoring of basic functions of some of the other components in the system such as drive motor speed, power supply voltages, and time-shared signal conditioning.



SIZE — 4.9 X 12.6 X 7.6 IN.
(1/2 ATR SHORT)
WEIGHT — 20 LBS
POWER — 20 VA (115 V, 400 HZ)
MTBF — 3,000 HR

FIGURE 40. MECHANICAL DATA RECORDER

The characteristics are assumed to be a reasonable product improvement of the present equipment. There is no known technical development that would lead to significant improvement in present electromechanical technology. It is expected that the tape unit can be made slightly smaller because the data requirements are less, and new integrated components such as A/D converters and signal multiplexing can contribute to a reduction in the electronic section. It is thus assumed that a new system could be built in the 12.6-inch 1/2 ATR short unit instead of the presently available 19-inch 1/2 ATR long unit. The primary characteristics that are assumed to be achievable are listed on Figure 40.

The primary advantage of this mechanical recording system is that it is a well-known and mature technology, and it can be developed with small technical risk. This system also has the advantage of a large memory capacity, and the capacity can be further increased by increasing the size of the tape magazine for a very small addditional cost.

The disadvantages heavily outweigh the advantages. The major disadvantages are the high maintenance cost and the large weight and size. The maintenance cost is high for two reasons:

> First, the system has electromechanical parts which are less reliable than parts not physically moving relative to each other. The best MTBF is expected to be 3000 hours. Since the technology is already mature, no new development is expected which will significantly improve the reliability in the foreseeable future without a major increase in unit cost.
>
> Second, the maintenance cost is also high because of the required maintenance to verify operation through periodic data extraction and analysis and to replace the tape and clean the recording heads and other mechanical parts. This characteristic is contrary to one of the primary design goals for the AIRS system - that of no required periodic maintenance.

The system has the disadvantage, particularly for Army helicopter application, of large weight and size. The system is relatively heavy because of the required mechanical parts including the tape reels and guides themselves, and the drive mechanism and motor. With crash protection, the weight is doubly increased because of the large minimum size of the tape reels that must be protected, increasing the size and weight of the protective material. The size and weight have been projected to be somewhat reduced from the current systems, but not significantly.

Tape systems typically have problems in the reliability of data recovery. Synchronization words must be recorded to allow the data to be identified and to compensate for possible data dropouts due to imperfections in the tape or problems with the recording signal level.

A major disadvantage of using electromechanical tape transports is their susceptibility to mechanical vibration and shock loads. This is a critical problem particularly in helicopters. Vibration isolation schemes would have to be employed in most installations, thereby further increasing size, weight, and cost.

Mechanical Audio System

Mechanical recording systems for audio recording are reviewed in Section 4.6. A system diagram and estimated typical characteristics are shown in Figure 41. The system consists of: the control circuits; necessary recorder electronics; the tape mechanism including tape reels, tape drive mechanism, and the recording heads; and the supporting functions such as power supply and failure monitoring.

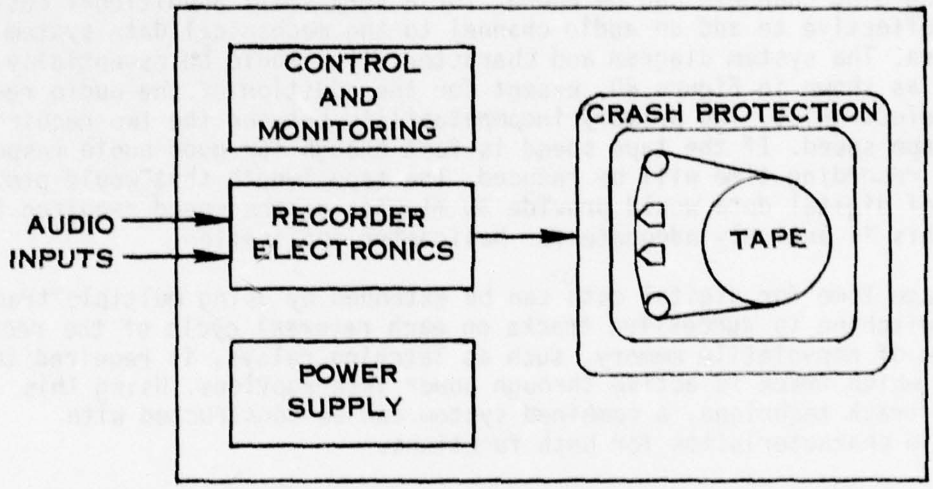
A typical system can record multiple audio channels. For purposes of illustration, this system records two channels; one from the common audio of the aircraft intercom and radio communication channel, the other from an area microphone.

The common audio system channel will record all voice communications between crew members in the cockpit and radio communications, except possibly for secure channel communications. This common audio channel will contain almost all verbal communications because the high noise level in helicopters normally requires helmets or headsets to be worn, essentially eliminating all other voice communications.

An area microphone channel is also added to record cockpit noise directly. The area microphone has been found to be very valuable in the analysis of commercial accidents by allowing the analysis of engine noises and other cockpit noises such as aural warnings and control movements. This channel is not expected to be nearly as valuable in a helicopter because of the high noise level. New-generation helicopters tend to have lower ambient noise levels. However, even though the value of attempting to record engine noise, blade noise, air noise and cockpit noise is questionable for helicopters, another channel can be added to a mechanical system for little added cost.

The system records in one direction until the end of the tape. It then reverses and records to the other end on another channel, as described in Section 4.6. This tape arrangement makes possible capacities up to 30 minutes, which is expected to be sufficient to record the majority of all communications that would be pertinent to a mishap. The tape itself is crash-protected to the same level as the data system.

The mechanical audio system has essentially the same basic advantages and disadvantages as the mechanical data system. It is based on a very mature technology and has a very large capacity. The number of channels and the length of time can be increased at relatively small cost. The system also is capable of broadband recording, allowing analysis of other noises besides voice.



SIZE — 4.9 X 10 X 7.6 IN.
WEIGHT — 18 LB
POWER — 15 VA (115 V, 400 HZ)
MTBF — 4000 HR

FIGURE 41. MECHANICAL AUDIO RECORDING SYSTEM

The system also has the same basic disadvantages as the mechanical data system, such as low reliability and high weight and size. Current systems have actual MTBF's as low as 700 hours. New systems are expected to have MTBF's approaching 2000 hours.

Mechanical Combined Data and Voice System

Since recording channels can be added for a very small addditional cost, it is cost effective to add an audio channel to the mechanical data system or vice versa. The system diagram and characteristics would be essentially the same as shown in Figure 40, except for the addition of the audio recording electronics. The primary incompatability between the two requirements is the tape speed. If the tape speed is fast enough for good audio response, the data recording time will be reduced. The tape length that would provide 3 hours of digital data would provide 30 minutes of the speed required for audio. This is entirely adequate for helicopter application.

The storage time for digital data can be extended by using multiple tracks, and by switching to successive tracks on each reversal cycle of the recorder. Some form of nonvolatile memory, such as latching relays, is required to indicate which track is active through power interruptions. Using this multiple-track technique, a combined system can be constructed with acceptable characterisitcs for both functions.

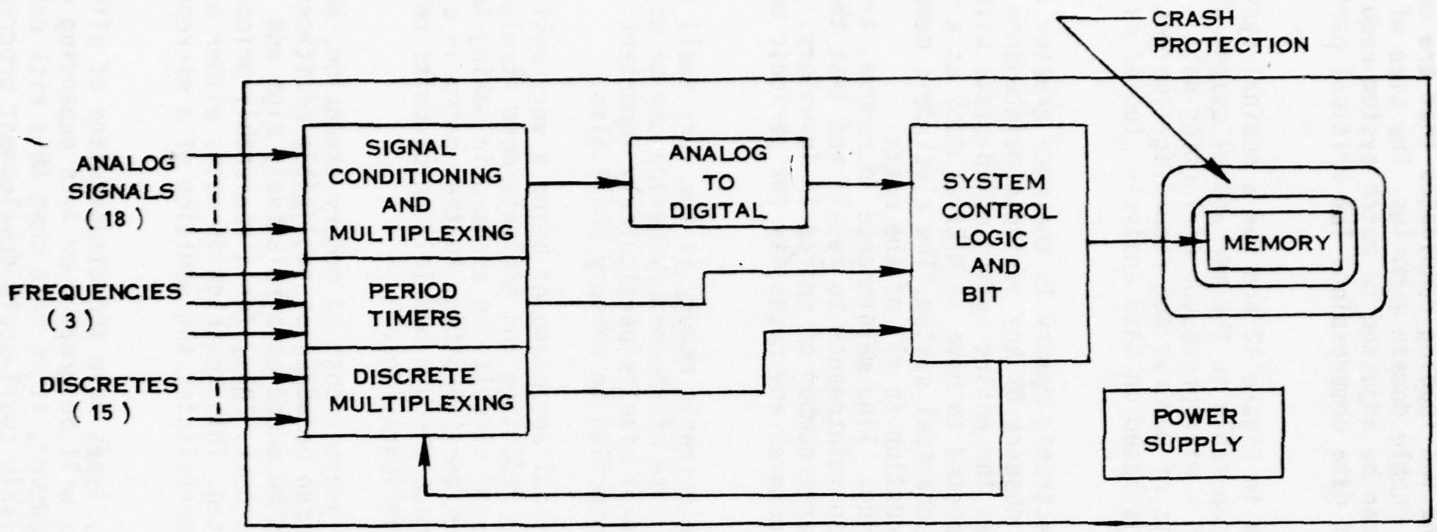
This system will have the same basic advantages and disadvantages as the two separate mechanical systems. If there is a requirement for both data and audio, this system has an obvious advantage over the two separate systems. Even if the basic requirement were only for data, if a mechanical system was chosen, the small additional cost for audio would make a combined system the preferred choice.

Electronic Memory Systems

Electronic Memory Data System

A functional block diagram of the candidate electronic memory system is shown in Figure 42. This diagram generally represents a number of different possible configurations that will be discussed later.

This system has essentially the same input circuits as the mechanical recording system; however, the control logic and data assembly section could have several forms. The control logic could be simple to give continuous fixed-format recording essentially the same as that used for the mechanical system. Alternatively, the control logic could be much more sophisticated using a microprocessor to perform system control and data compression functions as discussed in Section 4.7. This data compression is necessary to allow more information to be retained in the limited amount of electronic memory available.



SIZE — 5.0 X 6.0 X 7.40 IN.
WEIGHT — 8.0 LBS
POWER — 25 WATTS
MTBF — 10,000 HR

FIGURE 42. ELECTRONIC MEMORY DATA RECORDING SYSTEM

The memory section is some form of solid-state memory. Memory technologies were reviewed in Section 4.5. The two leading candidates that are considered as viable options were MNOS and bubble domain memories. The size of the memory is also a variable that can be adjusted to match system requirements for data rates and the degree of data compression. The critical parts of the memory are crash-protected.

The system characteristics given in Figure 42 are for a nominal system with capabilities essentially comparable to the mechanical system with which it is being compared. With a microprocessor performing data compression and with 100,000 bits of memory, the recording time would be approximately 1.5 hours. (This is based on data analysis studies as described in Section 4.7.)

The primary advantage of the electronic memory is the much greater reliability, practically unlimited life, and absence of any periodic maintenance requirements. An electronic memory makes the entire system solid-state with no moving parts. This system is expected to have an MTBF as much as a factor of four or more greater than the mechanical system. The electronic memory has additional advantages in the reduction in all of the costs associated with failures including: line maintenance to remove, troubleshoot, and replace the unit; shop maintenance to repair and test the system; and the maintenance of a large number of spares in inventory. The lack of any wearing parts also removes any necessity for periodic maintenance.

Another major advantage of the electronic memory is the very small size, weight, and power required. The size of the memory device can be as small as 1x1x0.5 inches. This small size is particularly important because it allows the memory protection to be very small also.

Electronic memory has the additional advantage of being a very positive and reliable medium, making data reduction and analysis more straightforward. No custom hybridization of circuits is assumed in making the size and weight estimate for this configuration. Further gains in size and weight reductions could be made through hybridizing circuits relative to other nonelectronic system configurations.

The primary disadvantage is the greater cost of memory expansion. Whereas in the mechanical system memory can be added at negligible additional cost, electronic memory can only be added at a relatively high and essentially constant incremental cost. Thus, for a reasonably priced system, the memory size is limited. This restriction means either a limited recording time and/or necessitates the addition of a microprocessor to provide data compression.

Some candidate electronic memory types have the disadvantage of slightly higher technical risk. This risk will be greater or less depending on the memory technology chosen. However, it is felt that this risk can be greatly reduced with a relatively small-scale development program to test and evaluate the prime technologies. Within the time scale of the development of the AIRS, the risk is expected to be acceptably small.

Electronic Memory Audio System

A functional diagram of the candidate electronic memory audio system is shown in Figure 43. The technology used in this system is discussed in Section 4.6.

The candidate system uses adaptive delta modulation to achieve discernible speech with a data rate as low as 8000 bits per second. The central circuitry incorporates an audio level trigger which only stores data when there is activity on the audio input.

This switch function inherently produces another form of data compression by making the recorded time less than real time. How much less is not known and must be determined by tests of typical communications in a helicopter, particularly during critical times. However, preliminary estimates show that the compression can be expected to be 3:1 to 5:1.

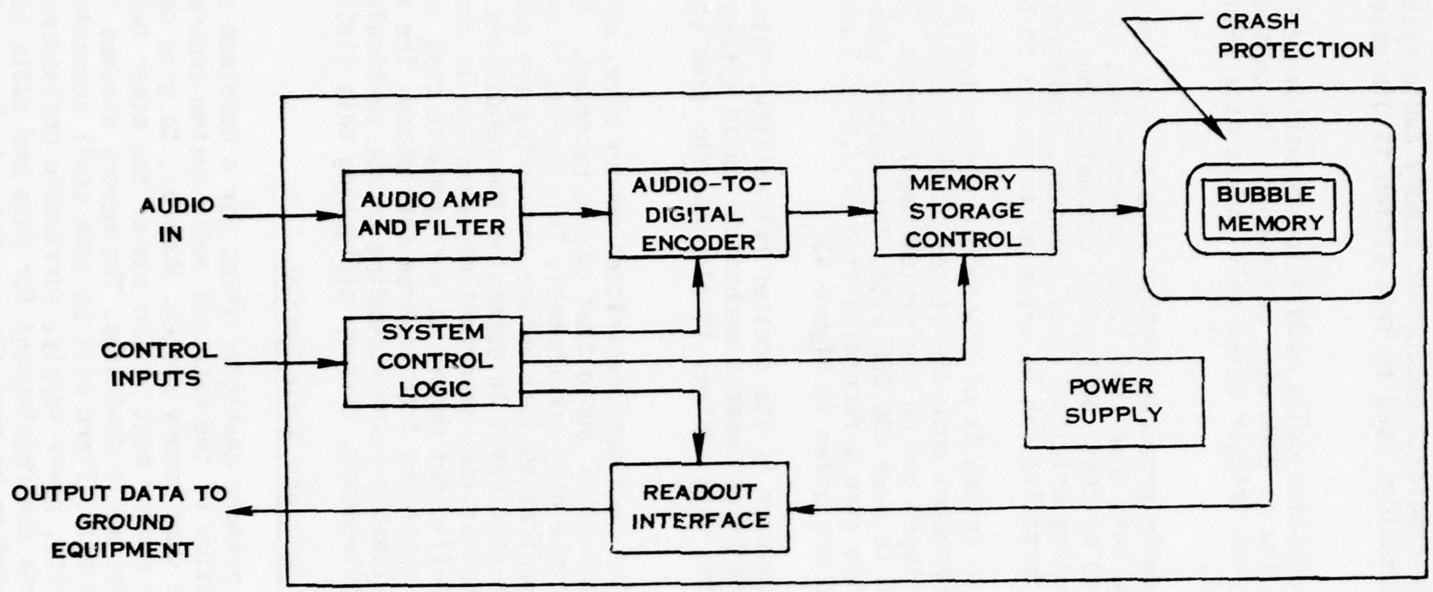
The memory in this candidate system is of the bubble domain type with the size of the memory being dependent upon the status of the technology at the time the system is developed and on the system requirements. The candidate system is assumed to have 400,000 bits. This memory size and the expected data compression give a recording time of 2.5 to 5 minutes. Other major characteristics are given in Figure 43.

The major advantage of the system is its greater reliability. This system has the same reliability advantages over a mechanical audio system as was discussed earlier for the data system; it also has the same size, weight, and power advantages.

The major disadvantage is the much more restricted memory size, which significantly reduces the amount of audio that can be recorded. Also, the system described can handle only one channel. This system is capable of recording the voice communication just before and during the accident. It may not be sufficient in some cases to determine the conditions that lead up to the accident. Another less important disadvantage is that this system does not have sufficient memory at a reasonable cost to allow broadband continuous recording from an area microphone. The area information may be of questionable value depending on the particular helicopter ambient noise environment, thereby mitigating this limitation.

Electronic Memory Combined Data and Audio System

The functional diagram and primary characteristics for a combined system are essentially the combination of the data and audio system separately. The data is combined in the same memory system. However, to give comparable performance the size of the memory must be the sum of the other two systems. Obviously the memory size for audio dominates. The memory assumed for this candidate system is 500,000 bits. There will be some small economies in common memory control circuits, power supply, survivable enclosures, and main chassis. However, unless the requirement for data and audio is very firm, this system is estimated to be much too expensive to be considered. The factors estimated for this configuration are shown in Table 33 along with the other systems considered.



SIZE — 4.5 X 5.5 X 6.0 IN.
WEIGHT — 5.8 LBS
POWER — 10 WATTS
MTBF — 8,000 HR

FIGURE 43. ELECTRONIC MEMORY AUDIO RECORDING SYSTEM

TABLE 33. SUMMARY OF SYSTEM CHARACTERISTICS

SYSTEM	Size In^3	Weight Lb	Power	MTBF Hours	Relative Price
Mechanical Data System	470	20	20 VA	3000	1.54
Mechanical Audio System	372	18	15 VA	4000	0.77
Mechanical Combined System	480	21	21 VA	2900	1.62
Electronic Memory Data System	220	8.0	25 Watts	10,000	1.0
Electronic Memory Audio System	148	5.8	10 Watts	8000	0.85
Electronic Memory Combined System	267	10.0	30 Watts	7000	1.77

Comparison of the Major System Classifications

The primary characteristics of the major system classifications are summarized in Table 33. It can be seen from this comparison that for data recording, the electronic memory has decided advantages over the mechanical system. Some savings is expected in initial cost; however, even more significant is the lower operating costs because of the higher reliability and lower maintenance.

This system will have a lower data capability, but the capacity is expected to be more than adequate for the great majority of accidents. Also, the technical risk is slightly greater, but the risk is expected to be minimal with a reasonable development·program.

Quantitative data is expected to be more valuable than voice data in analyzing the details of an accident. However, in some cases where voice data is of particular interest, or the cost of installation of a data system is very high because of few existing sensors in the vehicle, an audio system may be desired. The choice of the system in this case is less clear.

The mechanical system may have an advantage at the present time because of the much greater capability, although an electronic memory system is likely to be competing in the future. Some manufacturers are already studying the design of bubble memory chips with one million or more bits, a factor of 10 larger than the ones assumed in this candidate system.

Audio parameters are but one of many parameters in this study. Audio information is considered to be valuable in the absence of a cost-effective data system. A possible audio system is discussed in greater detail in Section 6.4.

The combined data and audio mechanical system is not considered further because of disadvantages already described previously for the electromechanical systems.

The combined voice/data electronic memory system is eliminated because of the high cost of hardware and the greater technical risk. The electronic memory data system is, therefore, selected as the system concept that offers the most functional capability at the lowest potential cost, weight, size and the highest reliability.

The following paragraphs of this section discuss several candidate variations of an electronic memory system. The discussion analyzes the trade-offs of the chosen system as a function of several variations within the broad system concept.

5.2 ELECTRONIC MEMORY DATA RECORDING SYSTEM DETAILS

The definition of the candidate AIRS systems using electronic memories is now considered in greater detail. The system configurations considered are the

result of various combinations of the major system options. These options are:

* With or without a microprocessor

* The choice of memory technology

* The size of the memory

The system configurations discussed are identified in Table 34. The major characteristics and features of each system are outlined and the applications, advantages, and disadvantages are identified. The basic functional diagram of all three systems is presented in Figure 42.

The parameter set and signal conditioning is the same for each system. The parameters, are those given in the candidate parameter list in Section 4.1, minus EGT, vibration, and separate flight "g" sensors. This discussion does not cover the minimum AIRS for impact which records only the minimum six parameters. That system is discussed in Section 6.3.

Systems With Simple Control Logic

System A

System A with simple control logic and 32K of MNOS memory forms the most basic and technically conservative system considered. With only simple control logic, all significant data is recorded continuously using the fixed-frame format. The recording time for a full set of AIRS parameters is thus limited to approximately 2.5 minutes. This time is sufficient to determine the details of most actual accidents, but it may not be sufficient to determine the conditions that led up to the accident.

The choice of MNOS memory is technically more conservative than bubble memory since the MNOS memory technology is more mature than bubble. Also, this technology can meet a wider temperature environment and thus make it easier to meet the survivability requirements. However, this memory is not as dense in terms of bits per unit volume and is thus larger and significantly more expensive than bubble memory in cents per bit. The memory system for this configuration should typically be constructed in a hybrid package in order to make the memory easier to protect.

System B

System B is the same as System A except that the MNOS memory is larger. The 100,000-bit memory will give approximately eight minutes of continuous recording, which will increase the probability that the cause of the accident will be determined. However, the cost and size of the memory package will be significantly greater.

TABLE 34. MATRIX OF CANDIDATE ELECTRONIC MEMORY SYSTEMS

	MEMORY SIZE			
MEMORY TYPE	32K MNOS	100K MNOS	100K BUBBLE	400K BUBBLE
SIMPLE LOGIC	A	B	C	D
MICROPROCESSOR	E	F	G	H

System C

System C is essentially the same as System B except that the memory technology is bubble. Since the size of the memory is the same, the recovery time is the same. However, since bubble memories are much more dense, only one 100,000-bit chip is required. This change makes the memory module considerably smaller and much less expensive. The bubble memory will slightly increase the technical risk since the memory chips proposed are just now becoming available, and there has also been little testing and experience with bubble memories at elevated temperatures. However, it is expected that these risks will be reduced during the time period of the AIRS development program.

System D

System D is the same as System C except that the memory is four times larger. This memory size will give more than 30 minutes of recording time, which is considered to be adequate for a large majority of all accidents and incidents. The memory system is constructed of a package containing four 100,000-bit chips. This package is thus considerably larger and more difficult to provide crash protection for. It is, of course, more expensive.

Systems With A Microprocessor

The remaining systems considered incorporate a microprocessor. The primary advantage of the microprocessor is that it allows data compression, which provides greater efficiency in the use of the limited electronic memory.

A microprocessor offers other advantages, several of which are listed below:

(1) The data input interface system is under computer control, allowing greater sampling format flexibility than is possible with hard-wired control.

(2) Much more effective built-in-test (BIT) is possible. The degree of self test is also subject to a design trade-off. However, based on implementing BIT on other digital systems, it is estimated that a 95% BIT probability of success can be achieved with no more than 5% additional hardware cost when the system is implemented with a microprocessor.

A non-microprocessor-based system can achieve approximately 60% BIT success probability with a 5% additional hardware complexity. For the non-microprocessor-based systems it may be mandatory to extract data periodically to insure system operation to an acceptable degree. This is the commonly accepted method in contemporary systems.

Including a microprocessor for no other reason than increasing the BIT effectiveness may alone be sufficient reason.

Specifically BIT can be accomplished in the following areas:

(a) Check of input interface using test signals.

(b) Read-after-write capability for MNOS memory or cyclic redundancy check for bubble memory.

(c) Instruction self-testing of the processor itself.

(d) Credibility check on input signals for out-of-range conditions, excessive rate of change, or lack of correlation with other related parameters. This allows a BIT to some degree of other components in the system such as the accelerometers and altitude sensors.

(e) Memory test for program memory.

(f) Watchdog timer to assure continued operation of the system.

(3) Additional computation and data manipulation can be performed on input data to make the output frame more efficient, such as combining the sine and cosine components of the synchro signals into one word using an arctangent routine and packing the most significant bit of words that are larger than eight bits into alternate locations.

(4) Interval timing necessary to simplify the interface for frequency inputs can be performed.

(5) Timing necessary to simplify the interface with the memory system can be performed.

(6) Bookkeeping functions to provide the proper turn-on and shutdown sequences can be performed.

(7) Logic necessary to assure that memory is not used when the aircraft is not actually flying can be provided.

(8) Software to selectively control data read/write to ensure that certain data would be retained in memory and not written over can be provided.

(9) An interface with standard ground data systems can be easily affected.

(10) An output to a possible ground readout unit, for use in installation and checkout, can be provided.

System E

System E is the same as System A except that a microprocessor is added. This microprocessor provides data compression and all of the other advantages listed above. The data compression will allow the 32,000-bit memory to record approximately 30 minutes of data, which is expected to be adequate for almost all cases.

System F

System F is the same as System E except that the memory is increased to 100,000 bits. This memory size will give approximately 1.5 hours of recording time. This time is assumed to completely meet the design goal for the system and allows complete coverage of most flights from take-off to landing. However, the system does have the disadvantage of a large and expensive memory.

System G

System G is the same as System F except that the memory technology is changed to the bubble type. Thus, this system has the 1.5-hour data capability with a much less expensive and smaller memory, which is a very desirable combination of characteristics.

System H

System H is the same as System G except that the memory is expanded by a factor of four. With data compression, this memory size gives a recording time of 6.0 hours, which is not considered to be of significant value in helicopter applications and would not justify the cost of the additional memory.

Comparison of Electronic Memory Systems

The relationship among the various systems in terms of recording time and estimated relative price is shown in Figure 44. The desired recording times and the relative price goal are also shown. The differences between the systems in terms of size, weight, and reliability are not enough to influence the choice between them.

It can be seen that System D is the only one that can meet the desired time requirements without a microprocessor. However, System G is only slightly more expensive, meets the full range of the desired time, and possesses all of the other advantages of using microprocessor. System E meets the minimum requirements for recording time and is near the price goal. This system uses the more conservative MNOS memory technology. System F is considered to be too expensive, and System H has more memory than is necessary.

Thus, the systems that are chosen for further study are G and E. These two systems are microprocessor-based and have either a 32,000-bit MNOS memory or a 100,000-bit bubble memory. The choice between the two is a question of recording time versus technical risk, with a slight price advantage for the bubble system.

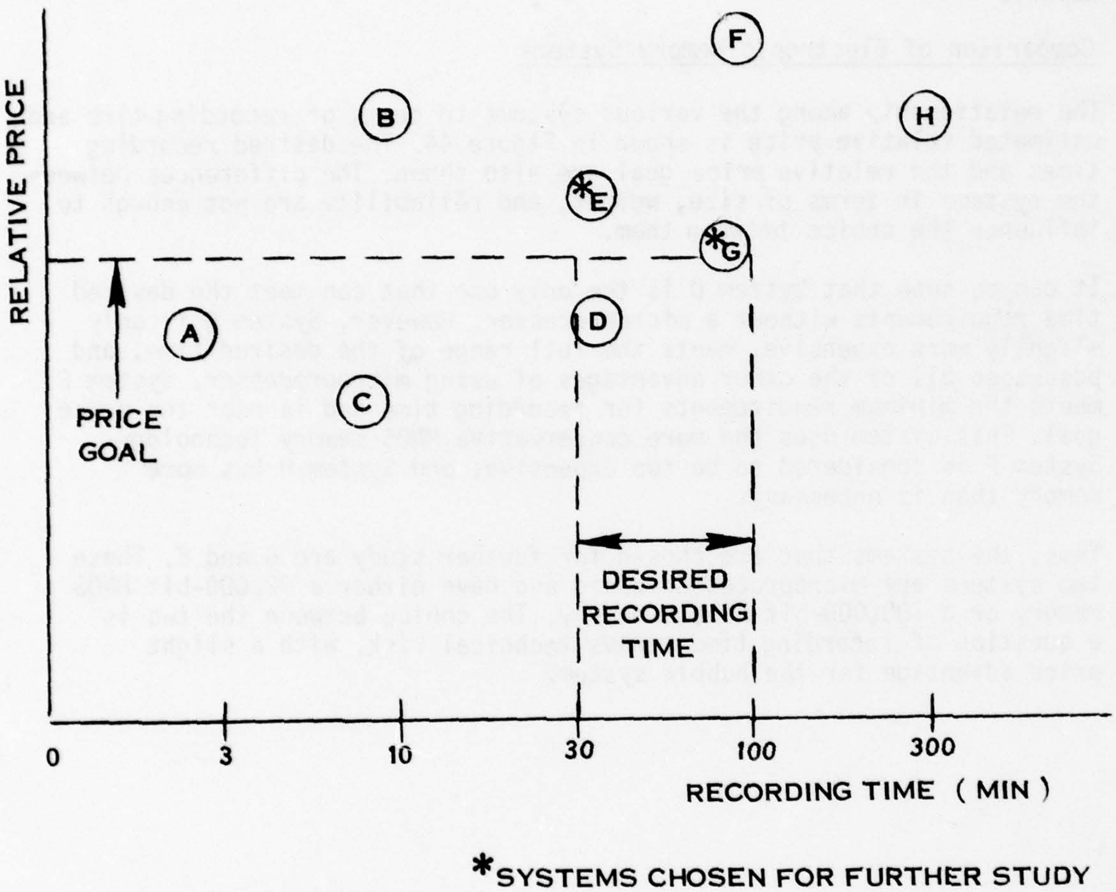


FIGURE 44. RECORDING TIME/PRICE COMPARISONS OF ELECTRONIC MEMORY SYSTEMS

6.0 SELECTED SYSTEM CONCEPT TRADE-OFFS

The previous section identified the major candidates for AIRS; discussed the characteristics, advantages, and disadvantages of each; and discussed the selection of the basic system configurations that seem to be the best choice for satisfying the AIRS requirements.

In this section, the proposed system concept is refined further by a trade-off study of the possible system variations. The variations to be considered are outlined in the following section. Next, the factors to be considered in the trade-off for each variable are discussed.

In many cases the trade-off factors have already been discussed in detail in earlier sections of the report. This section briefly summarizes these results in a common format.

6.1 SYSTEM VARIATIONS TO BE CONSIDERED IN THE TRADE-OFF STUDIES

The first item considered is the parameters to be recorded by the system. Involved in this trade-off is the effect of including that parameter in the AIRS system itself, such as the need for a new sensor and additional wiring. The parameters are considered on a one-by-one basis with special attention given to altitude, acceleration, and EGT.

Other variables considered in the trade-off study are:

(1) Memory technology

(2) Memory size

(3) Degree of crash protection

(4) System Operation through impact(s).

6.2 FACTORS CONSIDERED IN THE TRADE-OFF

The first factor considered is the performance of the system; that is, the degree to which the variable being studied affects the capability of the system as simply stated: "Gather and preserve data for use in investigating accidents".

The performance is extremely difficult to determine quantitively; however, is is important that good engineering judgement be used in determining the worth of an option. For example, if a change could be made that would greatly reduce the cost or weight but would also severely limit the usefulness of the system, that change would not be effective. On the other hand, if another feature can be obtained for little cost but which is of little value for the intended function, it should not be added.

The next factor in importance is usually cost, with the trade-off between capability and cost. Where necessary, the cost includes not only the initial cost but other related costs such as installation and maintenance.

Other important factors are weight, size, reliability, and maintainability. Weight and size are of particular importance in helicopter applications where auxiliary equipment such as AIRS should have minimum impact on the mission payload. Size is also important in the limited volume available in helicopters.

High reliability and ease of maintenance are very significant factors in the total cost of ownership of the system. Reliability and maintainability are also important for reasons beyond the measurable costs. These factors include maximizing the probability that when crash data is needed, the system will be operational. Also this system should have minimum impact on the operational readiness of the aircraft, and it should create minimum workload for maintenance crews.

6.3 RESULTS OF THE TRADE-OFF STUDIES

Parameter List Trade-off

The results of the trade-off studies as accomplished in Phase I are summarized in Tables 35 and 36. In Table 35 the UH-1H helicopter represents current helicopters, and in Table 36 the UTTAS represents new helicopters. The tables give the trade-off factors for all the parameters on a parameter-by-parameter basis, plus several other system variations. The trade-off factors tabulated are cost, weight, and size. Other factors such as reliability, performance, maintenance, and technical risk are more difficult to express in quantitative terms and are discussed in the text.

The deltas given are approximate values starting with an assumed basic system. This basic system includes signal input interface circuits for the first six parameters, a microprocessor control, a 32,000-bit MNOS memory, and the necessary supporting hardware including power supply, case, connectors, etc. The deltas for price are in percentages of the baseline system. The deltas for weight and size are given in pounds and cubic inches. The baseline for these deltas is given at the top of the table. The deltas include new sensors, where necessary, plus an estimate of the associated installation cost. The delta costs are in two columns: one for the change in the AIRS hardware itself and one for the change in the aircraft. The delta weight and size includes the AIRS hardware and the sensors but not mounting bracketry or wiring, which is dependent on locations. The following paragraphs give information that is helpful in interpreting these tables and discuss other related factors that are not shown on the tables.

The deltas for adding parameters cannot be defined precisely on a parameter-by-parameter basis for all parameters. This fact is particularly true when considering the input signal multiplexing circuits. Multiplex circuits are normally made to handle some fixed number of channels such as 8, 16, 24, etc.

TABLE 35. SUMMARY OF PARAMETER TRADE-OFF FOR UH-1H

		AIRS UNIT COST (%)	SENSOR & INST. COST (%)	WEIGHT (LB)	SIZE (in^3)
BASELINE SYSTEM		100	10	4.7	153
1	Airspeed	-	8.0	1.0	5
2	Heading	-	1.0	-	-
3	Altitude	-	1.0	-	-
3A	Altitude (High Resolution)	-	6.0	1.0	5
4	Vertical Acceleration	-	5.0	0.2	1
5	Longitudinal Accel.	-	3.0	0.2	1
6	Lateral Acceleration	-	3.0	0.2	1
MINIMAL SYSTEM		0	37.0	7.3	166
7	Pitch Attitude	2.0	1.0	0.3	6
8	Roll Attitude	0.7	1.0	-	-
9	Engine Torque	0.7	1.0	-	-
INTERMEDIATE SYSTEM		3.4	40.0	7.6	172
10	Rotor RPM	2.0	1.0	0.3	6
11	Engine RPM	0.5	1.0	-	-
12	Fire Detection Discretes	1.0	0.5	0.2	4
13	Chip Detector Discretes	0.3	0.5	-	-
14	Hydraulic System Press.	0.2	0.2	-	-
15	EGT	8.0	1.5	0.2	4
18	Longitudinal Cyclic Pos.	0.5	20.0	0.2	2
19	Lateral Cyclic Pos.	2.0	2.0	0.4	6
20	Collective Pos.	0.5	2.0	0.2	2
21	Tail Rotor Control	0.5	2.0	0.2	2
22	Vertical Flight Accel.	0.5	3.0	0.2	1
23	Long. Flight Accel.	0.5	3.0	0.2	1
24	Lateral Flight Accel.	0.5	3.0	0.2	1
25	Vibration	-	-	-	-
26	Radar Altitude	N/A	-	-	-
FULL SYSTEM		20.4	61.7	9.9	201
RECOMMENDED SYSTEM (with no EGT & Flt. Accel)		10.9	51.2	9.1	194
A	64,000-Bit NMOS Memory	16.0	-	0.5	5
B	100,000-Bit Bubble Memory	-11.0	-	0	0
C	Crash Protection	- 4.0	-	-2.8	-25
D	Operation Through Impact	- 2.0	-	-0.5	-10

TABLE 36. SUMMARY OF PARAMETER TRADE-OFF FOR UTTAS

		AIRS UNIT COST	SENSOR & INST COST	WEIGHT (LB)	SIZE (in.^{3})
BASELINE SYSTEM		100%	10%	4.7	153
1	Airspeed	-	1.0	-	-
2	Heading	-	1.0	-	-
3	Altitude	-	1.0	-	-
3A	Altitude (High Resolution)	-	6.0	1.0	5
4	Vertical Acceleration	-	5.0	0.2	1
5	Longitudinal Accel.	-	3.0	0.2	1
6	Lateral Accel.	-	3.0	0.2	1
MINIMUM SYSTEM		0	30.0	6.3	161
7	Pitch Attitude	2.0	1.0	0.3	6
8	Roll Attitude	0.7	1.0	-	-
9	Engine Torque	1.0	1.0	-	-
INTERMEDIATE SYSTEM		3.7	33.0	6.6	175
10	Rotor RPM	2.0	1.0	0.3	6
11	Engine RPM	0.7	1.5	-	-
12	Fire Detection Discretes	1.0	0.5	0.2	4
13	Chip Detector Discretes	0.3	0.5	-	-
14	Hydraulic Syst. Press.	0.2	0.2	-	-
15	EGT	10.0	2.0	0.2	2
18	Longitudinal Cyclic Pos.	2.0	1.0	0.2	4
19	Lateral Cyclic Pos.	0.5	2.0	0.2	4
20	Collective Pos.	0.5	1.0	-	-
21	Tail Rotor Control	0.5	2.0	0.2	2
22	Vertical Flight Accel.	0.5	3.0	0.2	1
23	Long. Flight Accel.	0.5	3.0	0.2	1
24	Lateral Flight Accel.	0.5	1.0	-	-
25	Vibration	-	-	-	-
26	Radar Altitude	0.5	1.0	-	-
FULL SYSTEM		23.4	53.7	8.3	191
RECOMMENDED SYSTEM (With no EGT & Flt. Accel)		11.4	43.7	7.7	185
A	64,000-Bit MNOS Memory	16.0	-	0.5	5
B	100,000-Bit Bubble Memory	-11.0	-	0.5	0
C	Crash Protection	- 4.0	-	-2.8	-25
D	Operation Through Impact	- 2.0	-	-0.5	-10

It is thus possible to add a signal, if it is of the same type as the existing signals, for almost no additional cost if there is a spare slot in the multiplex system. However, if there is no spare slot, the cost of adding a signal is significant because an additional or larger multiplex chip is necessary and, in some cases, an additional card will be necessary. After the multiplex chip has been added, further additional signals can again be added for a low incremental cost. The specific points at which these larger increases take place depend on the details of the particular design and on the order in which parameters are added. Table 35 illustrates this effect by arbitrarily showing a larger increase at approximately the correct interval.

Table 35 shows no AIRS unit costs for the first six minimum parameters because the capability to handle these signals is assumed to be a part of the baseline system on which these deltas are based. The approximate costs of procuring and installing sensors and for wiring the new and existing sensors are shown in the Sensor and Installation Cost column. The weight and volume of the additional sensors, excluding wiring, is also shown. Subtotals are shown for various complete systems of interest.

An additional 10% is shown for installation cost to cover the basic installation of the unit itself and the associated power wiring and circuit breakers. For example, for a total system which recorded the six basic parameters, the additional sensors and the installation cost are expected to add approximately 37% to the hardware price of the baseline system. The weight and volume, excluding wiring, are expected to be 7.3 lb. and 166 cu. in.

The next signal added (pitch) is assumed to require a change in the multiplexer. It also requires signal conditioning and demodulation for two signals to handle the synchro-type signal. The next signal (roll) is assumed to be added in a spare slot in the multiplexer, but it still requires the synchro signal conditioning. Enginer torque is also an AC signal on the UH-1H, requiring demodulation.

Rotor RPM again requires special signal conditioning to decode the frequency signal. Once this new signal conditioner is added, engine RPM can be added at a much smaller additional cost. Likewise, the first new set of discretes are likely to require an expanded discrete multiplexer. The next discretes can be added very inexpensively.

EGT can be seen to be a very significant addition. This is due to the special conditioning and compensation necessary for a thermocouple type of signal. Special wires and pins are also required, increasing the cost of the unit and the installation. This increase is so large that the inclusion of EGT in the parameter list is not justified. This parameter is thus excluded in the recommended system. If the signal becomes available as a high level DC, it can be included at little added cost.

New sensors are needed for all control positions on the UH-1H, which accounts for the larger installation costs. Lateral cyclic position was chosen as the

point at which a significant expansion at the system input interface would have to be made again.

In order to obtain the desired accuracy in flight acceleration, three more accelerometers are necessary. Taken as a group they increase the cost of the system by more than 10%. These sensors were not included in the recommended system because the additional information gained was not judged to justify the additional expense. Flight acceleration was placed relatively low on the priority list. Also, measurement of flight acceleration is not completely lost. Even though the accelerometers scaled for impact acceleration are likely to have poor resolution at flight acceleration levels, some indication of flight acceleration will be possible.

Separate vibration sensors and vibration analysis circuits were considered to be too expensive to add to the system. A separate vibration monitoring system for the complex vibration environment in a helicopter was expected to add 10% to 20% to the cost of the system. However, the extraction of information on vibration by special processing of the existing acceleration data can be considered and holds some promise of giving useful data. This approach would add negligible cost.

Radar altitude is listed as not applicable to the UH-1H. A radar altimeter is not standard equipment and to add one for AIRS purposes only would be completely unjustified.

In the trade-off associated with the parameter list there is little influence from the factors of reliability, maintainability and technical risk. All of the circuitry added as parameters are of high reliability and technical maturity. The new sensors are also highly reliable and involve no new development. The adding of separate sensors does add to the maintenance burden. The system will be designed to give the maximum automatic testing of any added sensors. However, maintenance actions will be necessary to test these sensors and replace them if necessary. Of necessity, some will be in difficult locations. This maintenance burden is expected to be small, however, and not sufficient to eliminate the use of those proposed.

The recommended system for the UH-1H is thus one that records all parameters except EGT and separate flight accelerometers. The equipment itself is expected to be priced approximately 11% more than the baseline system. The total installation, including new sensors, is expected to be approximately 50% of the baseline price.

UTTAS Helicopter

The summary of the trade-off factors for the UTTAS is seen to be similar to that of the UH-1H. The significant difference is that more sensors are available on the UTTAS, which reduces the installation costs. First, an airspeed sensor is available, reducing the minimum system cost. Other differences are noted as follows:

Engine torque is a DC signal which requires a simpler signal conditioner. However, two are required for the two engines. EGT is also more expensive because of the two engines. The UTTAS already has two of the control position transducers and one of the flight accelerometers, which accounts for other differences. The UTTAS also has a Radar Altimeter, the output of which is recommended for recording. The AIRS unit cost is slightly higher because of the greater number of signals due to the two engines and Radar Altitude.

The recommended system for the UTTAS also excludes EGT and additional flight acceleration sensors. The unit price is again approximately 11% more than that of the baseline system. However, the installation and sensor costs are down to approximately 44% because of the fewer new sensors required.

Memory Technology, Memory Size, and Recording Time Trade-Off

Additional trade-offs of possible system variations are given at the bottom of Tables 35 and 36. These factors are the same for both helicopters. One of the most important trade-offs is between memory size and recording time. This trade-off becomes very involved in memory technology. This trade-off has already been treated briefly in Section 4.5, and the memory choices are also discussed extensively in Sections 6.3 and 7.2. However, the deltas are given here for comparison purposes.

The approximate deltas are given for doubling the 32,000-bit memory to give approximately one hour of recording time with data compression. The cost penalty can be seen to be a significant 16%. However, the deltas are also given for changing the memory to a 100,000-bit bubble memory. Here the cost is actually reduced by approximately 11%, while the recording time is increased to 1.5 hours. The equivalent time with a MNOS memory would increase cost 32%, giving about 43% difference in system cost between the two memories for the same storage. The technical risk of the bubble memory is somewhat larger. However, the cost and performance advantages are so great that it is recommended that this memory be seriously considered.

Crash Protection Trade-Off

Crash protection is discussed extensively in Section 4.8. The negative deltas for removing the crash protection is given in the tables. It can be seen that the cost impact of the protection is nominal. The larger impact is in the weight and size necessary to provide the protective material. The maintenance cost will also be somewhat larger because of the memory being inside the protective enclosure. However, the memory components themselves are expected to give MTBF's on the order of 30,000 to 50,000 hours. The maintenance disadvantage would thus be small. The total additional cost for crash protection is expected to be no more than 5%. Army accident statistics on fire alone show fire possible in at least 5% of the accidents with crashworthy fuel systems. The crash protection is thus judged to be worth the cost.

Operation Through Impact Trade-Off

The factors involved in operation through impact are discussed below. The approximate negative deltas are given here for comparison. It can be seen that the cost and weight are small. The primary negative effect is maintainability.

The design goal considered here stems from a desire to reconstruct the impact acceleration profiles through the crash sequence such that a more complete assessment of aircraft survivability can be made.

From an AIRS unit mechanical point of view, the box structure can be designed to maintain operational integrity for peak accelerations of 150 g's with only a minor effect on cost and weight as discussed in Section 4.8. Unit repairability is degraded since the interconnection scheme within the unit would be changed to eliminate quick-release hold-down elements for the modules. In addition, the outer chassis and interior modules would be rigidly bolted together. However, the relatively high MTBF of the AIRS unit tends to offset the decreased level of repairability.

From an aircraft installation point of view, the unit mount can be designed to survive by assuring the necessary strength in the chassis attachment points and airframe receiving structure, with a small weight penalty.

From an impact sensor installation viewpoint, the greatest degree of survivability is afforded by placing the triaxial cluster inside the AIRS unit. This, however, has the disadvantage of not being able to place the sensing point where desired in some cases due to the box size. For sensor locations external to the AIRS unit, extra care will have to be taken in installing the triaxial cluster and wiring to minimize conditions which would lead to wiring breakage due to the acceleration levels and differential movement of adjacent structures that would cause tearing or slicing of the interwiring.

From an electrical operating standpoint, power must be maintained in the unit and to the sensors for the desired time duration. The simplest solution may be to exercise the same care in airframe wiring to improve power-carrying wire and connection survivability.

Providing for AIRS self-power for up to five seconds beyond the initial impact requires electrical energy storage either by a self-contained battery or through short-term charge storage in a power supply capacitor. The battery source is not recommended because of maintainability reasons. A capacitor of reasonable size can be provided which will furnish approximately 0.1 second of energy sufficient to maintain operation with external power cutoff with a minor effect on weight and cost. Since 0.1 second is short compared to the design goal, it is recommended that the system rely on wiring interconnection integrity for power through the desired period.

The effect of AIRS operation through impacts on airframe installation and wiring is a function of the particular location of system elements. Section 7.6 addresses this objective with regard to installation in the UH-60A.

Recommended System Per Phase I

The recommended general system concept from Section 5.0 was one with an electronic memory and a microprocessor. This section has further refined the system as being one that:

(1) Records all signals from the candidate parameter list except EGT and does not have separate sensors for impact and flight accelerations or separate means for recording vibration.

(2) Uses a 32,000-bit MNOS memory.

(3) The memory is protected for a crash environment per civil transport requirement as ammended herein.

(4) The system is designed to operate through impact but with reliance on external essential buss battery power.

Using the above characteristics as determined in Phase I, Phase II of the study further refined the recommended AIRS as described in Section 7.0. One further change was made to the recommended system per Army request. This change added back in one axis of flight acceleration (the vertical axis). This was also included in the Phase II study.

Minimum Impact AIRS

The basic approach in concepting the Mini-AIRS was to continuously record input data together with a synchronization code in a fixed format as shown in Table 37.

It should be noted that the parameters shown in the table reflect the results of a meeting with Army personnel after the contract was awarded, wherein a candidate parameter list and priority order was established. The parameters were identified as those for a Minimum Impact Measuring AIRS. The list differs from the original statement of work in that altitude replaces attitude (pitch and roll).

Concept

A Minimum Impact AIRS System was concepted to provide a minimum-cost version of a crash recording system. Overall performance is inferior to the microprocessor version of AIRS from a data storage, self-health and data availability analysis standpoint. However, it does represent a minimum-cost version of a system which would still provide significant pertinent data to aid crash investigation.

TABLE 37. FIXED-FRAME FORMAT MINI-AIRS

WORD NO.	PARAMETER
1	Sync Word
2	Sync Word
3	Altitude
4	Heading (Sine)
5	Heading (Cos)
6	Airspeed
7	Vertical Peak Acceleration
8	Longitudinal Peak Acceleration
9	Lateral Peak Acceleration
10	BIT

Figure 45 represents, in block diagram form, the Mini Impact AIRS. This diagram is shown utilizing EAROM as the nonvolatile memory. A minimum cost system would incorporate 8K bits of storage, which represents 100 seconds of data prior to and through the impact. Use of a larger memory would tend to favor use of a bubble memory device from a cost standpoint.

A 100K-bit bubble memory would increase storage time to approximately 20 minutes. Interface with a bubble memory would be somewhat different from that displayed in Figure 45 for the EAROM, since the bubble memory is basically serial in nature; however, the general overall approach is similar.

Details

In this system, time is implicit since recording is performed on a continuous basis. All words are fixed at eight bits and the sampling rate is once per second.

The three accelerations are differentially received and filtered, and subsequently fed to dedicated peak-and-hold circuits which will capture and hold during the one-second sampling interval the highest peak acceleration, either positive or negative. These peak-and-hold circuits are reset after readout into memory.

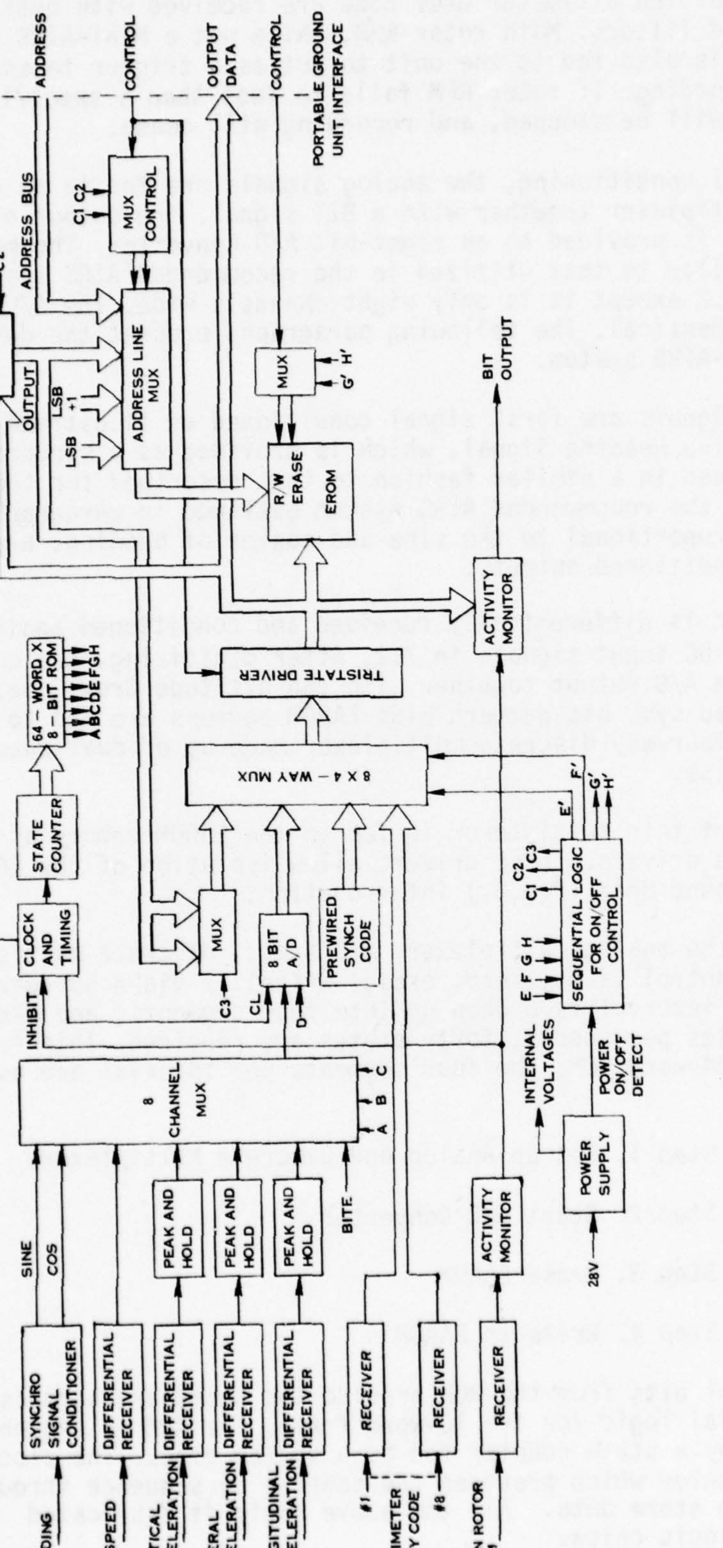


FIGURE 45. MINIMUM IMPACT AIRS

Eight bits of the altimeter Grey code are received with dedicated comparators and filters. Main rotor RPM, while not a Mini-AIRS required parameter, is also fed to the unit to act as a trigger to enable and disable recording. If rotor RPM falls to less than a specified RPM, the unit clock will be stopped, and recording will cease.

After signal conditioning, the analog signals are fed to an eight-channel multiplexer together with a BIT signal. The output of the multiplexer is provided to an eight-bit A/D converter. The multiplexer chip is similar to that utilized in the recommended AIRS system in paragraph 7.2 except it is only eight-channels wide. The A/D converter is identical. The following paragraphs present the details of the Minimum-AIRS system.

The input signals are first signal conditioned as illustrated in Figure 45. The Heading Signal, which is provided as a synchro input, is conditioned in a similar fashion to that described for the synchro signals for the recommended AIRS system outlined in paragraph 7.2. DC voltages, proportional to the sine and cosine of heading, are provided as conditioned outputs.

The airspeed is differentially received and conditioned again, as described for DC input signals in 7.2. After digitizing, the analog signals, the A/D output together with the altitude Grey Code, and the pre-wired sync bit pattern plus EAROM address are fed to an eight-wide four-way discrete multiplexer made up of dual-quad multiplexer chips.

The output of this multiplexer is fed to the EAROM memory as shown via tristate drivers. These drivers allow isolation of the EAROM for Portable Ground Unit (P.G.U.) interrogation.

Control of the analog multiplexer, A/D start, discrete multiplexer and EAROM control (i.e., read, erase, write) is via a hardware ROM. Each sample interval is broken up into four segments, and since there are 10 samples per second, forty states are required. This is supplied by a 64-word ROM. The four segments per interval are as follows:

Step 1. Set up Analog and Discrete Multiplexers

Step 2. Start A/D Converter

Step 3. Erase EAROM

Step 4. Write in EAROM

Eight control bits from the ROM provide the necessary signals to provide the sequential logic for the 10-word frame. The ROM is sequenced through its states by a state counter fed by a system clock. The clock also feeds a 12-bit counter which provides the address to sequence through the EAROM to store data. All the above logic is fabricated using CMOS logic chips.

In order to ensure continuity of data through power interruption and shutdowns and, therefore, ensure time correlation, special hardware precautions are taken. These are illustrated by the clock labeled sequential logic for on/off control. Control bits E, F, G and H are modified as appropriate by this logic, and three additional control bits are generated as shown (C_1, C_2, C_3).

Upon power loss, the following sequence of events would occur prior to unit shutdown.

Step 1. EAROM address set to all 0's

Step 2. Eight LSB of 12-bit address counters are written into EAROM memory location zero.

Step 3. EAROM address set to all 0's = 1

Step 4. The four most significant bits of 12-bit counter are written into this address

Step 5. Unit is allowed to be depowered

Upon restoration of power, the following sequence of events must occur.

Step 6. EAROM address set to all 0's

Step 7. The eight LSB's of 12-bit counter are preset to the contents of the EAROM at this address

Step 8. Contents of EAROM address, all 0's are erased

Step 9. EAROM address set to all 0's + 1

Step 10. The four MSB's of 12-bit counters are set to the contents of the EAROM at this address

Step 11. Contents of EAROM address; all 0's + 1 are erased

Step 12. The 64-word state counter set to zero

Data reduction is somewhat complicated since no provisions are made to ensure that complete frames of data are stored prior to termination of recording after a power interruption. However, truncated data can be recognized by premature sync words.

A Portable Ground Unit (PGU) interface is provided which essentially turns over the address, data, and control lines for the EAROM to an external unit or a microprocessor-controlled unit. The PGU initiates sequencing through the EAROM starting at the last address written in (data in address LSB and LSB + 1) plus one by sensing an overflow condition, skipping the first two address, and back to the last address written in. This data would be transferred to a tape cassette.

The PGU would also do verification by a second reading of the EAROM and a reading of the tape cassette. Built-In-Test capability is somewhat limited; however, some hardware is provided to achieve a degree of unit integrity checking. This hardware consists of activity monitors on the EAROM data lines which are activated whenever the main rotor RPM is active. Additionally, an analog BIT signal is included in the output frame format.

Periodic data dumping and analysis (i.e., looking for proper BIT word, sync codes, reasonableness of data, etc.) would be required to achieve a reasonable probability of successful operation of the unit in an Army-wide application. To achieve 98% probability of success would require unit checkout every 200 hours by ground readout of data.

The important parameters, i.e., size, weight, cost, and reliability for the minimum AIRS are tabulated. A narrative on differences between the recommended AIRS and Mini-AIRS is also provided.

AIRS Versus Minimum Impact AIRS

While the unit cost difference between minimum impact AIRS and AIRS is close to 2:1, the performance improvements of the recommended AIRS must be critically examined. In addition, the significantly greater level of BIT must be considered in the AIRS, which utilizes a microprocessor. This may mean that the mini-AIRS, not having a microprocessor, would require periodic data extraction and validation to insure proper operation. This, in turn, leads to a higher cost of ownership and may offset a major part of the increased initial cost of the recommended AIRS over the mini-AIRS.

The additional data storage achieved by data compression and expanded parameter list (as outlined in paragraph 7.1) will undoubtedly be of additional benefit in crash and incident investigations. It is not possible to quantify, in dollars, the improved performance based on available information.

Detailed advantages of using a microprocessor in AIRS are outlined in paragraph 5.2. In addition to BIT improvements, use of a computer facilitates ground replay and parameter readout by possibly eliminating a computer in the ground unit.

The following table summarizes the estimated major characteristics of the two systems:

	MINIMUM IMPACT AIRS	RECOMMENDED AIRS
Number of parameters	6	18 analog, 18 discretes
Data Storage Time (min.)	1.7	30 minutes (average)
Weight (pounds)	4.7	7.62
Size (cu. in.)	98	190.5
Relative Cost	0.5	1
Power (Watts)	10	25
Reliability (MTBF hrs.)	20,000	10,000

In summary, the parametric analysis capability, in terms of numbers of parameters and amount of storage, of the recommended AIRS is significantly greater than that of mini-AIRS (factor of 3), while the mini-AIRS enjoys approximately a factor of two in reduced failure rate, size, weight and initial cost. Based on this comparison and other reasons as stated above, it appears that the recommended AIRS provides more value per unit cost.

6.4 ALTERNATE SYSTEM - VOICE STORAGE

Solid-State Voice Storage Unit Implementation

Since the study of solid-state techniques of voice storage showed potential capability for a limited system, a description is provided here.

Recording

Implementation of a solid-state voice recorder is shown in block diagram form on Figure 46. The system shown is configured for a single-channel audio input and utilizes the techniques described in Section 4.6 for converting the analog voice input into a digital representation suitable for storing in a solid-state memory. The memory utilized is a serial bubble memory as described in Section 4.5. Implementation and operation of the system is as described in subsequent paragraphs.

The voice signal is input to an audio interface. This provides the necessary circuit isolation, impedance match and amplification between the Voice Recorder and aircraft pickoff point. The voice signal is next filtered by a bandpass filter of 300 to 3 KHz bandwidth. The band-limited signal is then input to a forward adaptive delta encoder for digitizing.

The audio encoder is operated at a sampling frequency (f_1) of 9.5 KHz and has its step size magnitude controlled by an envelope detector operating off the audio input signal. The envelope signal is itself encoded by means of a linear delta encoder operating at a sampling frequency (f_2) of 500 Hz. The two digital signals are combined via a multiplexer.

Encoding control logic is used to determine when storage is to take place and prompts the memory system to receive a data package. The encoding control receives signals from the interphone system press-to-talk buttons (PTT), which indicate when voice is present. (A separate input aircraft interlock derived from a source such as weight-on-wheels switch or engine-running switch can be utilized to preclude irrelevant voice storage during ground or aircraft maintenance operations.)

Before storage takes place, the audio input signal is also inspected at the output of the envelope detector for the voiced and unvoiced periods when the PTT button is depressed. When voice is detected, a synchronization code and time code are written as a header to the digitized voice.

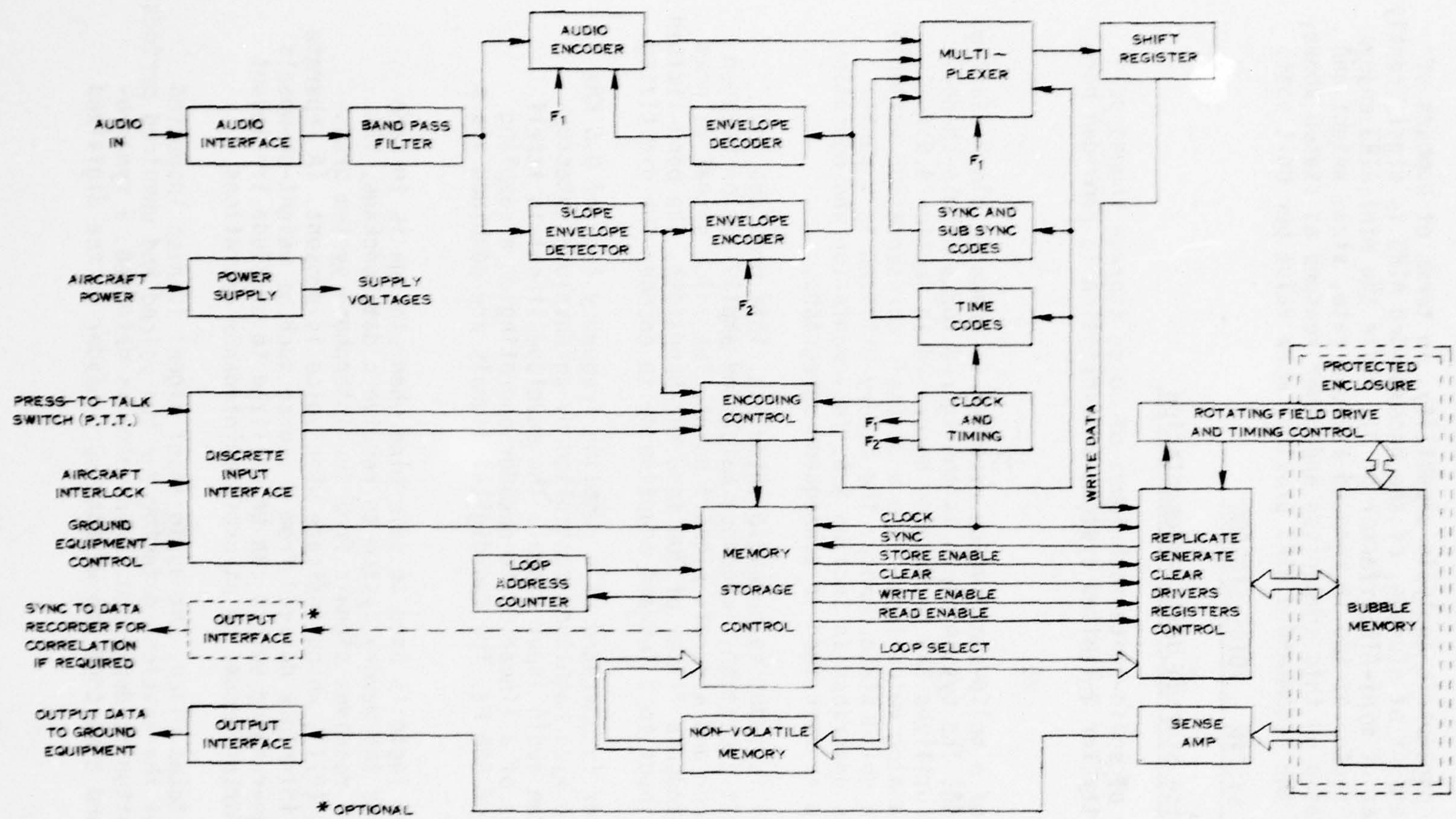


FIGURE 46. SOLID-STATE VOICE RECORDER BLOCK DIAGRAM

A Signal Block multiplexer combines these various signals together into a combined data stream comprising a synchronization word, time code, encoded voice and encoded envelope. A shift register provides a short buffer storage to provide a time margin in the assembly of the message and to enable the voice and unvoiced decision to be made. The time code generator consists of a counter running off of a precision clock which is also used to provide the various frequencies utilized in the system.

The Memory Storage Control Logic is responsible for operating the bubble memory storage and coordinating the writing of incoming encoded voice signals into correct locations. The Bubble Memory is essentially a serial storage device which is partitioned in sections, i.e., a 500K memory may be comprised of five loops of 100K each. The storage control and loop address counter keeps track of the present location being used in the memory. Appropriate control signals are also issued to synchronize the writing of data in memory and to select the appropriate loop circuit.

The loop address and memory address locations are lost if a power interruption occurs. Therefore, the present loop in use is stored in a nonvolatile memory. This enables correct start-up at power restoration and precludes destroying any voice data that might otherwise be inadvertently overwritten.

The memory module is contained in the crash-protected enclosure with a small amount of support circuitry. Other memory support circuits are housed outside this enclosure for generation of the rotating magnetic field, reading, writing, and clocking.

A power supply accepts aircraft power and generates all the necessary internal voltages, and an interface is provided for connection to ground support equipment to allow for readout of the memory.

Recovery

Figure 47 typifies the voice recovery circuitry. Voice reconstruction is obtained by detecting the synchronization words and demultiplexing the digital data to provide the time codes so that the data can be arranged in its correct time relationship.

The encoded voice signals are then assembled into a register which is clocked out through a demultiplexer to separate the encoded audio and encoded envelope signals. The voice signal is then decoded using the same sampling frequencies used for encoding.

If separate voice and data storage units are used, time synchronization is usually required between them, so that upon readout the voice and data can be time-correlated. If this implementation is selected, the voice unit can provide a time code for use by the Data Storage Unit for this purpose.

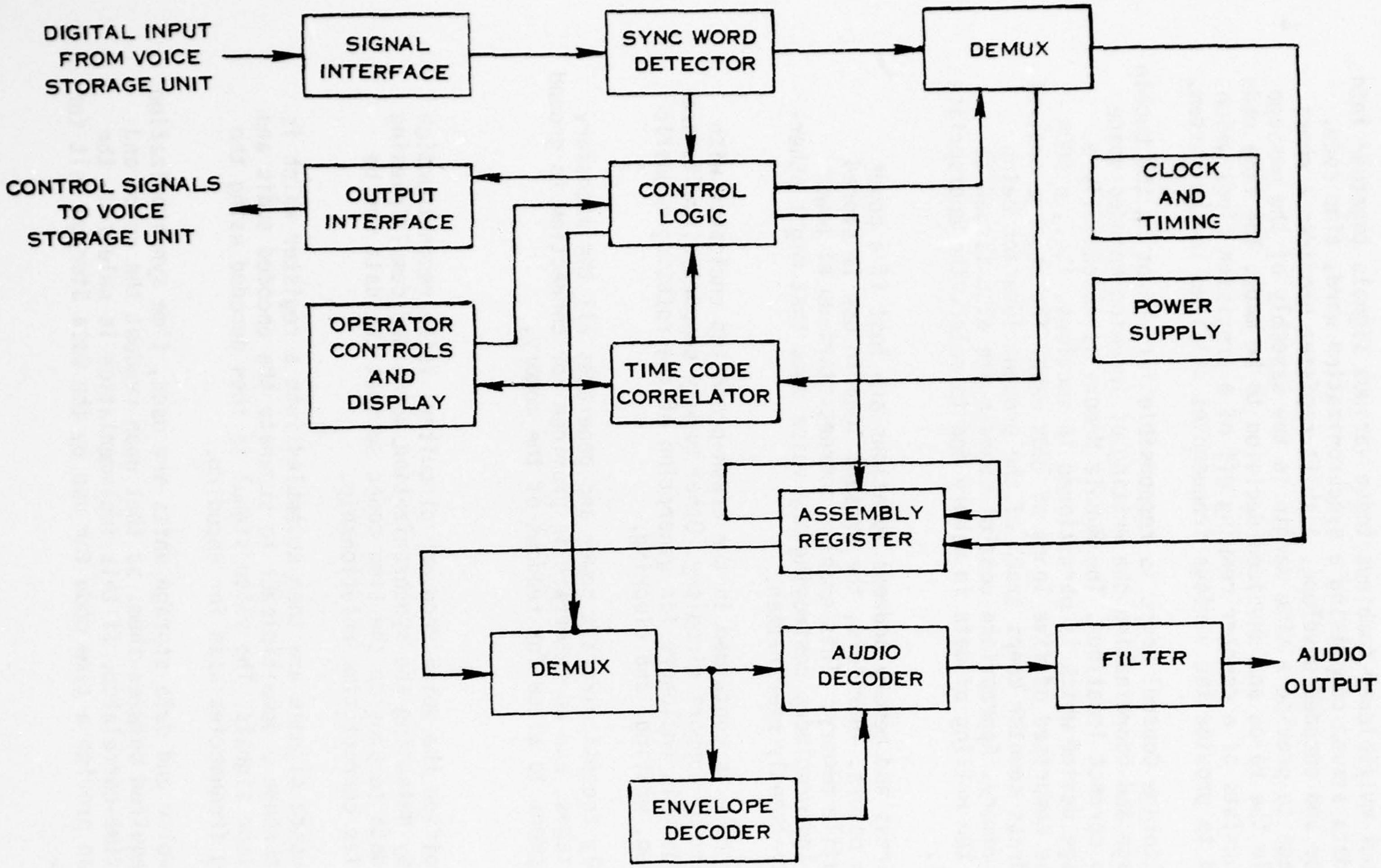


FIGURE 47. GROUND SUPPORT EQUIPMENT FOR REPLAY OF SOLID-STATE VOICE RECORDER

7.0 RECOMMENDED AIRS DESCRIPTION AND ANALYSIS

7.1 GENERAL SYSTEM DESCRIPTION

The recommended AIRS concept is described in detail and the important factors are analyzed herein. The overall system is depicted in Figure 48.

The system includes sensors to supply signals in addition to signals already available on the aircraft. The signals are fed to an AIRS electronics unit which conditions and converts the analog signals to digital information. The digital information is processed by a microprocessor and stored selectively in a protected solid-state memory module. When an incident occurs which requires readout and investigation, the protected memory module is read out using a portable ground unit. If the AIRS unit is intact in the aircraft it can be read out in place. The PGU records the data on a Phillips type cassette. The cassette is then either played into a telephone transmission scheme or physically transferred to existing computer facilities. The data is then reconstructed in real time and analyzed by the Army ground computer facility and dispatched to the investigation team.

The airborne portion of the system (specifically the AIRS electronics unit) represents advanced technology, but within the state of the art. The airborne sensors are available off the shelf devices.

Versions of the portable ground unit currently exist for commercial applications and could be ruggedized if the Army deems necessary for operational deployment.

The equipment for voice grade telephone transmission of data directly to existing computer facilities from any remote site having telephones also exists. Ground Software Programs can readily be written using developed techniques to tabularize and/or reconstruct data in real time for investigative team analysis.

Table 38 lists the recommended input airframe parameters for the AIRS.

The selection rationale for the airborne portion of the recommended system is given in Section 6.0, with the choice being primarily directed by capability, cost, weight, volume, maintainability and reliability. In this section, the ground portions of the system are also addressed. The recommended system can be utilized as concepted for any of the four aircraft studied in Phase I (i.e., UH-1H, AAH, CH-47, and UTTAS) and is applicable to other Army Aircraft with either the existing instrumentation or by adding sensors per paragraph 4.2. In certain cases, resistors and capacitors may have to be altered on the input circuits, or an occasional jumper provided to account for signal electrical differences. However, the system is basically the same for all four aircraft and can be flexible and readily expandable. Two spare analog inputs and four spare discrete inputs are implicit in the hardware complement specified. Addition of further levels of multiplexing is readily achiev-

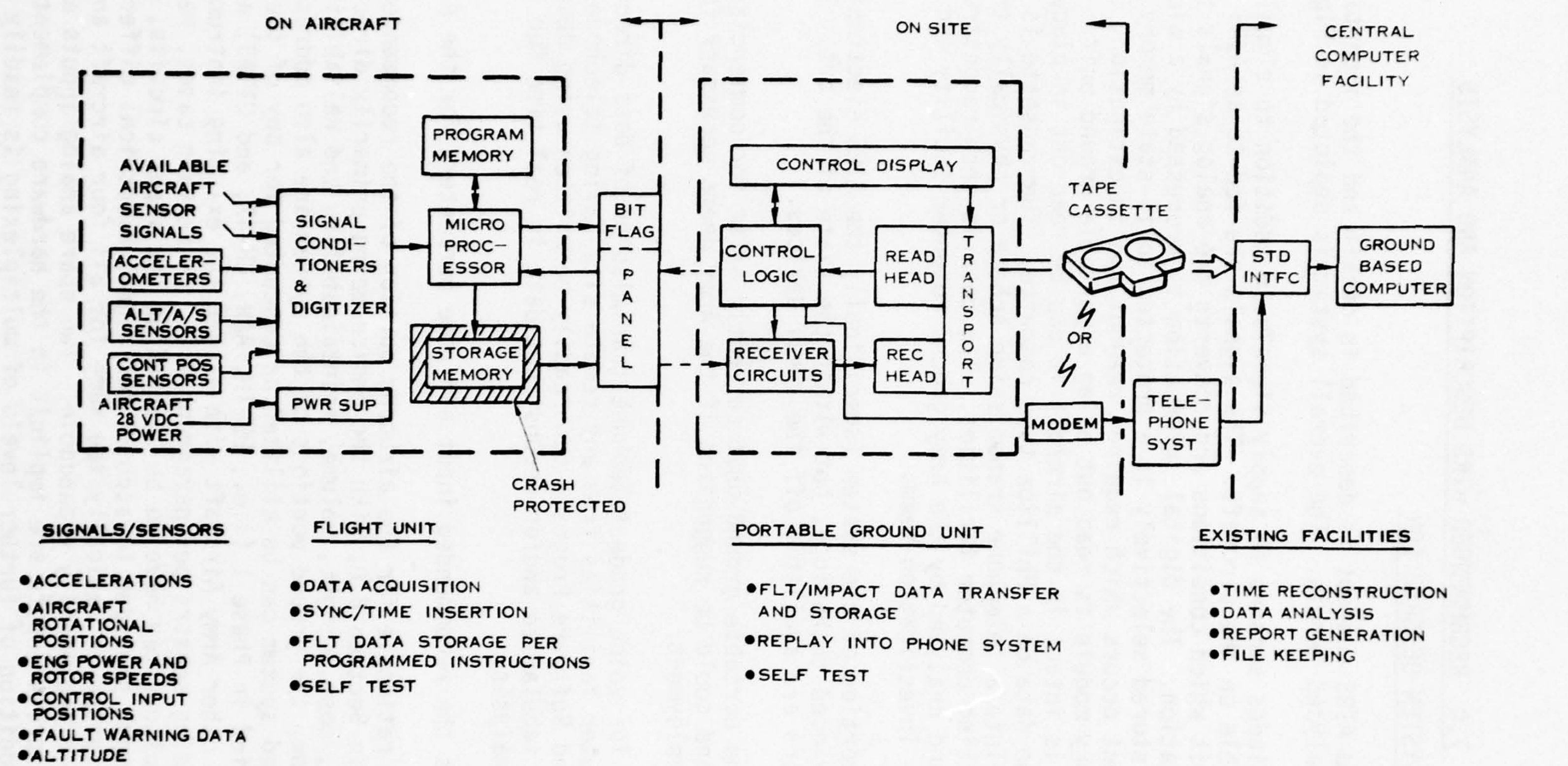


FIGURE 48. ACCIDENT INFORMATION RETRIEVAL SYSTEM (AIRS)

TABLE 38. RECOMMENDED AIRS PARAMETERS

1. Airspeed
2. Heading
3. Altitude
4. Vertical Acceleration, Flight and Impact
5. Longitudinal Acceleration, Impact Only
6. Lateral Acceleration, Impact Only
7. Pitch Attitude
8. Roll Attitude
9. Engine Torque (Each Engine)
10. Rotor RPM
11. Engine RPM (Each Engine)
12. Fire Detection Discretes (Each Engine)
13. Chip Detection Discretes (Each Engine)
14. Hydraulic System Discretes - No. 1 & 2 Systems & Backup
15. Longitudinal Cyclic Position
16. Lateral Cyclic Position
17. Collective Position
18. Pedal Position
19. Radar Altitude (when available)

Note: Elapsed time is a parameter that is included and is self generated within AIRS.

able since I/O control is basically achieved by microprocessor program memory, which can be changed. Expansion or changing in the area of data processing is also readily achievable with a program change. The reserve capability of the 8085 microprocessor chosen, in both processor time and memory addressing capability, is felt to be more than adequate for AIRS expansion.

The following paragraphs describe in detail the various sections of the system and the design guidelines that can be used. The description given is based on installation in a UH-60A as being representative of a new aircraft application.

7.2 AIRBORNE HARDWARE

Detailed Block Diagram Description

Design Life

The system electronics unit as described in detail below can be implemented using all solid-state devices. Therefore, the unit has a design life which can easily meet the 5,000-hour life requirement as stated by the Army. One device type that is number-of-operating-cycles dependent is the electrically alterable read only memories (EAROM's) which are used for nonvolatile data storage in the protected memory modules. This is addressed in section 4.5, wherein it states that current EAROMS are capable of 10^5 erase/write cycles. Since the protected memory will hold approximately thirty minutes of flight data, each location will be erased and altered two times per hour. Since the design life is 5,000 hours, this results in approximately 10^4 cycles. Therefore, a margin factor of ten exists in the cycle limit for the devices.

Signal Conditioning and Multiplexing

Synchro Signal Conditioner (Type II)

Three synchro signals are provided as indicated in Figure 49. The signals are handled in an identical fashion. Time-shared conditioning was considered, but since only three signals fall into this category, the added multiplexing and control complexity did not compare favorably with three dedicated conditioners. Each synchro is first fed to a Scott-T transformer which converts the three-wire synchro input to two 400 Hz signals proportional to the sine and cosine of the phase angle. Use of the transformer provides excellent common-mode rejection and DC isolation. One-half of a quad analog switch package in conjunction with the secondaries of the Scott-T provides synchronous demodulation. One-half of a quad operational amplifier chip, together with discrete resistors and capacitors, filters the resultant outputs to provide DC voltages proportional to the sine and cosine of the angle. Filter break frequencies are set typically at 10 Hz. A bias is provided to the filter amplifier so that the sine and cosine are always positive; therefore, a unipolar A/D converter can be utilized.

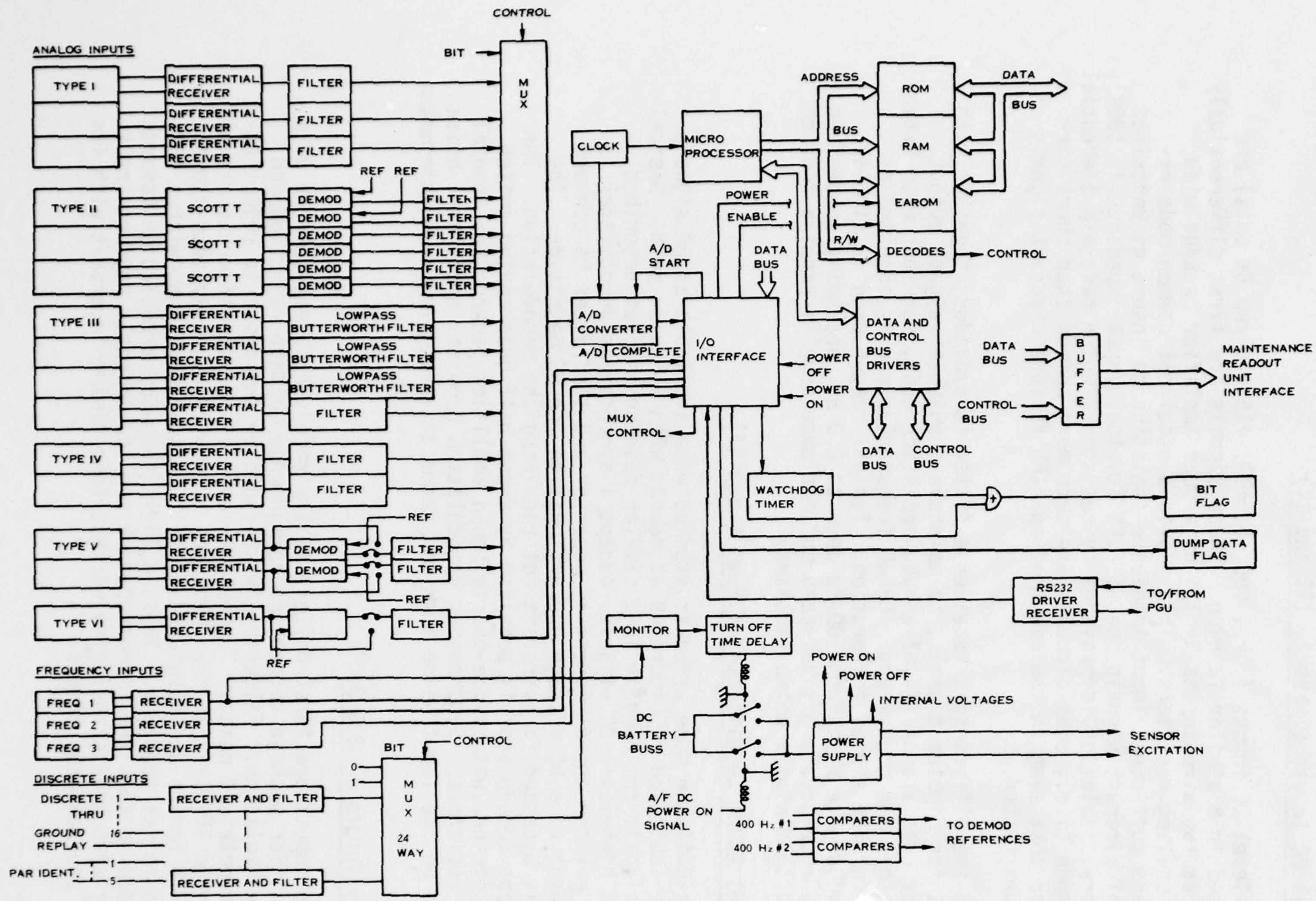


FIGURE 49. AIRS BLOCK DIAGRAM

High-Level DC Inputs (Types I, III and IV)

All high-level DC inputs (i.e., VDC +5, +10, +15 $\pm$10 and 5K pots) are conditioned in a similar fashion. These signals are first differentially received as two-wire inputs by 1/4 of a quad amplifier package with external scaling resistors. This provides excellent common-mode rejection and sufficient input impedance isolation to insure no undesired loading of aircraft signals due to AIRS (typical input impedance is 100K). Furthermore, isolation is provided by resistors, which have a preferential failure mode (i.e., open circuits are much more common than short circuits), so that even in the event of an AIRS failure aircraft signals will be unaffected.

Following the differential receiver a filter is provided, together with an offset for bipolar signals, to maintain a unipolar signal output. The filter consists of 1/4 of a quad amplifier chip, together with external resistors and capacitors. Break frequencies can be adjusted as required for the signal in question. Typical ranges used in similar applications have been from 100 Hz down to 2.0 Hz, depending on desired frequency response (e.g., airspeed and altitude usually require heavier filtering to minimize noise problems).

High-Level AC/DC Conditioners (Types V and VI)

Certain signals on some aircraft studied were available as AC signals. These are indicated in Figure 49 as demods with a bypass path. Basically, the signals are handled in a similar fashion to that described above for high-level DC signals, except a synchronous demodulator is provided between the differential receiver and the filter to convert the AC input to a DC voltage proportional to the AC magnitude. The circuit is bypassed for aircraft not requiring the demodulation. The synchronous demodulator is provided by a one-half quad analog switch package together with a one-quarter quad amplifier package and several discrete resistors. Synchronous demodulation provides additional noise filtering on the input noise since it tends to cancel any nonsynchronous signals.

Frequency Inputs 1, 2 & 3

Frequency inputs are first differentially received by one-quarter of a quad amplifier package to provide common-mode voltage rejection and impedance isolation. Filtering is provided on the input to reject undesired electrical noise. The output level of the amplifier is clamped to TTL logic levels. If the frequency is low (i.e., less than about 1KHz) it is fed to an integrated circuit phase-locked loop with a 16:1 countdown in its feedback. Thus, a 16:1 frequency translation upwards is provided so that the microprocessor can conveniently measure input frequency with good granularity without long timing intervals with its internal programmable timers.

Discrete Signal Conditioning and Multiplexing
(Input discretes 1 through 16, 5 parameters and 1 ground replay discrete)

A dedicated divider network and filter is provided on each input to scale them to a common value of voltage. The scaled values are multiplexed by an 8-way plus a 16-way multiplexer chip with built-in decoding. The output of the multiplexers is fed to a time-shared comparer, which is one-quarter of a quad amplifier. Control of the multiplexer would be via the microprocessor. Scan rate would be such as to ensure monitoring all discretes, plus a BIT discrete, at least once per second.

Analog Multiplexing

A 16-port and an 8-port multiplexer chip are provided to multiplex the above conditioned AC/DC signals into a common A/D converter. A BIT signal is also provided to verify proper operation of the multiplexer chip and A/D converter. The analog channels are addressable under computer control; thus, high sampling rates are achievable on desired channels, such as acceleration. The lowest sampling rate would be set up at once per second for each parameter.

A/D Converter

A 27-pin DIP provides all the logic plus the ladder network for an eight-bit successive-approximation analog-to-digital conversion. An external comparer is required in conjunction with this chip. It provides, under computer command, the eight-bit digital equivalent of the presently supplied output of the analog multiplexer. Conversion time is less than 20 microseconds.

Microprocessor and Support Circuitry

An 8085 microprocessor was selected. It is packaged in a 40-pin dual in-line package (DIP). It has a bidirectional multiplexed data/address bus and fully-decoded T^2L-compatible control outputs. It can support up to 64K bytes of mixed RAM and ROM, and can address 256 input ports and 256 output ports, thus providing a great expansion capability. Four vector interrupts are provided. The instructions set includes conditional branching, decimal as well as binary arithmetic, logical, register to-register, stack control, and memory reference instructions and is directly compatible with the earlier 8080 series microprocessor.

The clock and timing is included in the 8085, and only an external crystal is required. It generates all signals required to interface with RAM, ROM and I/O components. A bidirectional bus driver is included to provide high system T^2L fan out. It also provides isolation of the data bus from memory and I/O, thus allowing the use of slower memory and I/O. The 8085 has adequate speed to handle AIRS software requirements, since it operates with a 1.3-microsecond instruction cycle. Various support chips are provided to operate in conjunction with the 8085 processor to provide necessary input/output support functions. The system

Controller and Bus Driver function is also provided by the 8085.

Programmable Input/Output Interface

The Programmable I/O Interface is a general-purpose link to the inputs and outputs of the 8085. It is contained in a 40-pin DIP. One I/O Interface chip is used to perform the following functions:

The first is associated with the inputting of analog and discrete data, as well as control of the analog and discrete multiplexers. The A/D output and discrete signal conditioner are provided as input to the programmable interface.

Random access under software control is provided on the analog, frequency, and discrete multiplexers by seven output control bits. An A/D start control bit is also provided, as well as a power strobe for the non-volatile memory storage. Two additional outputs are shown: (1) to annunciate a unit fault (BIT); and (2) a unit determination that data should be read out (Read Data).

The Programmable I/O Interface also provides a simple standard interface with the Portable Ground Unit. The interface is programmed by the 8085 to operate using virtually any serial data transmission technique presently in use. The interface accepts the data characters in parallel format and converts them into a continuous serial data stream for transmission.

Simultaneously, it can receive serial data streams and convert them into parallel characters for the 8085. The interface will signal the processor whenever it can accept a new character or whenever it has received a character. It is capable of working in a synchronous mode from DC to 56K Baud, and in the asynchronous mode from DC to 9.6K Baud. Error detection (parity, overrun and framing) is included. An RS232 Driver/Receiver has been provided to buffer the input and output of this interface.

Address Decoder

Address decoding is provided as required to enable appropriate chips from the higher order 8085 address bit decodes.

Random Access Memory

Hamilton Standard's operating experience with the 8080 series of processor indicates that 256 words of RAM are adequate for AIRS software tasks. This is implemented with two 256 X 4-bit PROM chips available in a 22-pin DIP. RAM would be utilized for temporary buffering of data to be written into EAROM and for scratch-pad usage.

Read Only Memory

Two thousand words of ROM were estimated for the AIRS operational program. This is implemented by two 2K X 4-bit chips available in 18-pin DIPs. Initial system checkout could be made using PROMs (Programmable Read Only Memory) which are pin-for-pin interchangeable with the final ROMs.

Watchdog Timer

A hardware watchdog timer is provided to detect and annunciate, via the BIT indicator, a program hangup. Unless periodically updated under software control, the watchdog timer would time out and be "ored" with a software generated fault discrete from the I/O Interface.

Nondestruct Electrically Alterable Read Only

As discussed in paragraph 4.5, two choices of memory were considered to be suitable to AIRS application. These are EAROM and bubble memory. EAROMS were selected for the recommended system primarily because bubble memories are untested at high temperatures. 32K bits of EAROM in 8K bit chips were selected custom interconnected in a hybrid package. EAROMS do have the advantage of being randomly addressable. Several locations can be reserved such that when power is removed, the address of the last location of EAROM written into is stored together with the elapsed time. Upon restoration of power the writing into memory is picked up where it left off, and elapsed time is contiguous. If these precautions are not taken, useful data might be written over and data retrieval could become difficult.

Power Supply and Control

Inverter

An inverter is provided which converts input 28 VDC into required internal voltage busses. Excitation of potentiometers necessary for readout of signals on certain aircraft is also provided. Power supply design would be consistent with the fact that the AIRS comes directly off the battery on a dedicated electrical buss. Therefore, some aspects of Mil-Std-704 need not be adhered to. For example, the normal operational requirement through a 50 millisecond power interrupt need not apply since no buss switching will occur. The design guidelines for the AIRS airborne electronics included further on in this section addresses this subject.

Automatic Power Control

Since the AIRS is directly off the aircraft battery through a switch which is pulled in when the aircraft is prepared for a start, and can only be shut down internally when the main rotor speed drops below a predetermined value after a suitable time delay, AIRS operation cannot

be interrupted. This is also shown in Figure 49. In addition, the AIRS circuit breaker is located adjacent to the battery relay box and is not located on the circuit breaker panel where it could inadvertantly be pulled. Therefore, AIRS operation is automatic with power actuation and AIRS cannot be interrupted during emergency shutdown procedures.

AC Power Reference Circuits

As shown on the system block diagram, comparers are included which take in the 400-cyclic reference voltages. These reference voltages are required for synchronous demodulation of the synchro and AC signal inputs. Since these voltages are required for AC signal reference purposes only, milliwatts of power usage are incurred.

Maintenance Readout Input/Output Interface Circuits

As shown in Figure 49 a buffer is included to interface with a maintenance readout unit. This is explained further in section 7.5, since it is a maintenance related function only and is not part of the AIRS operational circuitry. This output interface allows the processor to communicate with the external unit and provide data words as selected from the external unit. Six discrete input lines are shown on the referenced block diagram, one to signal the AIRS processor that a maintenance readout mode is requested and five lines to provide coded particular parameter readout request data.

System Design Guidelines for AIRS

Scope

This section defines the signal inputs, outputs, and performance guidelines for the Accident Information Retrieval System (AIRS). This section is written to accommodate signals from the four aircraft investigated in this program.

System Description

The AIRS unit samples various analog and discrete data under microprocessor program control. It compares the sampled data against fixed and floating limits; it also outputs properly formatted data to an Electrically Alterable Memory (EAROM) when limits are exceeded or at a minimum output rate as applicable. The data is read using a Portable Ground Unit (PGU) which dumps the data onto a cassette contained in the PGU. Two display drives exist to energize cockpit displays, one to indicate a requirement to dump data and one to indicate an AIRS unit fault.

An additional display output interface exists to allow real-time readout of selected parameters for maintenance purposes only.

The following documents apply to the AIRS system design guidelines.

EIA Standard RS 232-C Interface between data terminal equipment

AD-A055 590 UNITED TECHNOLOGIES CORP WINDSOR LOCKS CONN HAMILTON --ETC F/G 1/2
PRELIMINARY DESIGN OF AN ACCIDENT INFORMATION RETRIEVAL SYSTEM --ETC(U)
APR 78 H R ASK, M E MOFFATT, I HUGHES DAAJ02-76-C-0058

UNCLASSIFIED HSER-7342 USARTL-TR-77-51 NL

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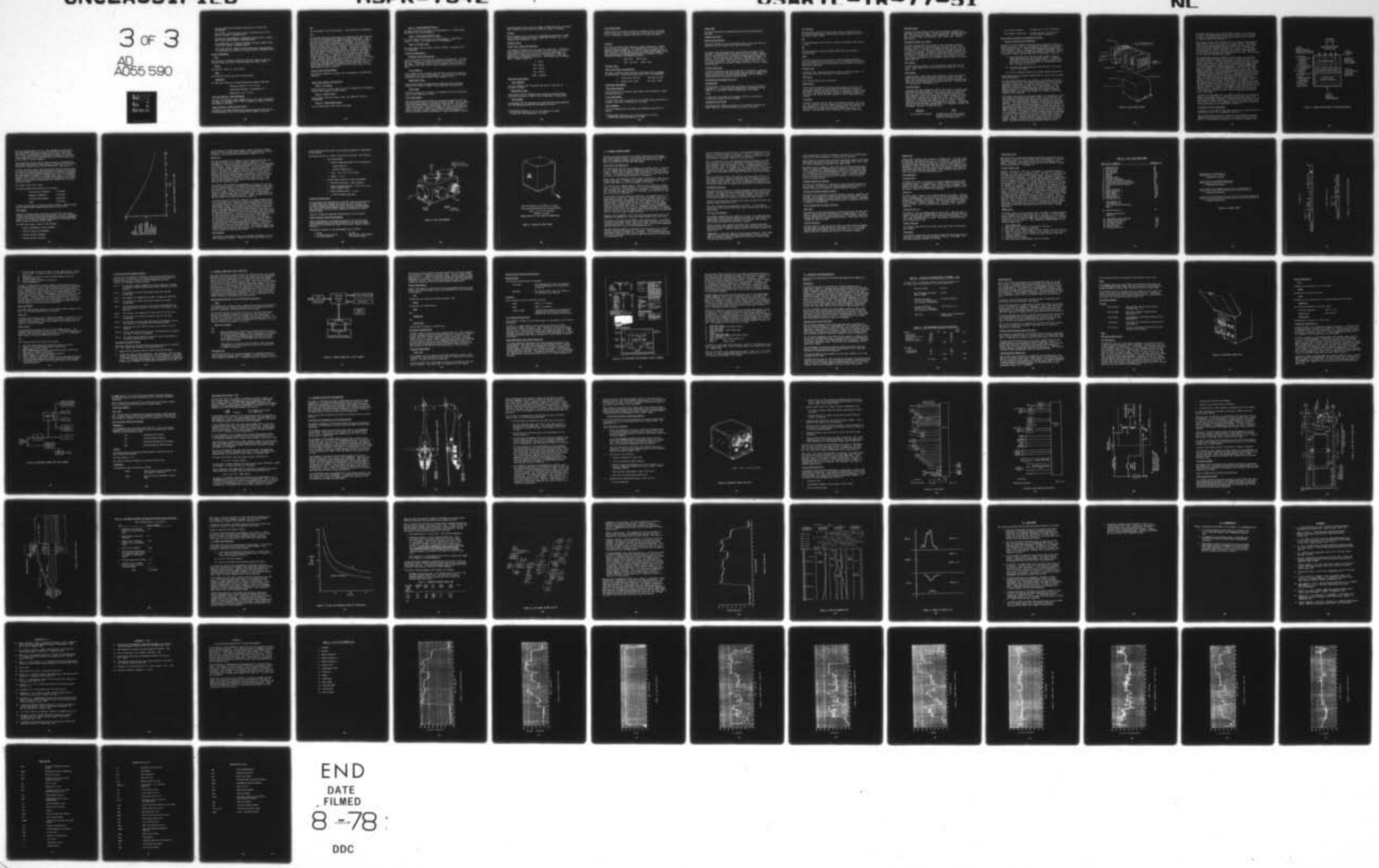

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and data communication equipment employing serial binary data interchanges.

MIL-STD-704D Electrical power aircraft characteristics and utilization of (except as ammended herein).

MIL-STD-461A Electromagnetic interference characteristics, requirements for equipment (except as ammended herein).

MIL-E-5400M Class 1A Electronic equipment, airborne, general specification for (except as ammended herein).

FAR 37.150, TSO C51a Federal aviation regulation, crash survivability requirements for commercial transport (except as ammended herein).

General Requirements

Size

The AIRS shall fit within an envelope of 200 cubic inches or less with width and height less than 6 inches and length less than 7 inches.

Weight

The AIRS shall weigh less than 8 pounds.

Power

The AIRS shall consume less than 25 watts average.

Temperature

The AIRS shall endure the following temperature ranges as specified:

Continuous operation - 54 C to +55 C

Intermittent Operation - 30 minutes @ 71 C

Nonoperating - 60 C to +85 C

Crash Survivability - AIRS Data Module

Per FAR 37.150 TSO-C51a, except immersion time in salt water increased to four weeks, and exposure time to 1100^{o}C increased to 1 hour to allow for the effects of cool down.

Impact Tolerance - AIRS Electronics Unit

The design of the AIRS electronics unit shall be such that the units can function through a 150g, 10-millisecond duration impact in any axis.

EMI

The requirements of MIL-STD-461A apply. (See note below for exceptions)

Note:

MIL-STD-704D should not be specified in its entirety with regard to power. The AIRS will be powered from a dedicated 28 VDC battery buss. Power will not be interrupted during normal or emergency conditions except for possible causes which are connected to an incident. In any case, the AIRS unit resets after power restoration and stores data relating to elapsed time when power is down. Therefore, only a few data points will be lost or garbled during any time interval. In addition, a keyed connector will be used to the battery relay box. Because of the above, certain requirements of Mil-Std-704D and 461A for transient overvoltage, polarity reversal, and EMI susceptability with regard to input power should not be invoked. In addition, nickel cadmium batteries exhibit a normal maximum voltage range of 20 to 28 VDC with a nominal value of 24 VDC. Voltages outside this range are generally the result of a failure in the battery or battery charging circuits or in the battery buss structure. Therefore, specified normal operation should be over a 20-to 28-VDC range with degradation acceptable outside this range. By not invoking MIL-STD-704D in its entirety the size, weight and cost of the AIRS electronics can be minimized.

Signal Processing Requirements

The following categories of signals shall be accepted in the quantities specified.

Signal Types, Ranges, and Quantities

Type I - DC Voltage

Three ranges (0-5 V, 0-10 V and 0-15 V) of DC voltages must be handled by resistor value changes for three channels.

Type II - Synchro Inputs

Three standard three-wire synchro inputs, per ARINC 407, shall be accommodated.

Type III - Potentiometer Inputs

Four 5K potentiometer inputs shall be accepted.

Type IV - Potentiometer/VDC Inputs

The input signal could be either a 5K potentiometer or a $\pm$10VDC signal. Two channels shall be accommodated.

Type V - Potentiometer/VAC/VDC Inputs

The input signal could be either a 5K potentiometer, a $\pm$5VDC 400 Hz signal, or $\pm$10VDC. Two channels shall be accommodated.

Type VI - VAC/VDC Inputs

The input signal could be either 8-15VAC or 0-8VDC. One channel shall be accommodated.

Conditioner Requirements

AC/Synchro Signal Conditioning

The AC and synchro inputs shall be synchronously demodulated. The output shall be filtered by a single-pole low-pass filter with a 3-db point at 6Hz $\pm$50%. The reference signals shall be obtainable from two sources. The synchros shall feed a Scott-T input to generate sine and cosine outputs.

Input Impedance

Input impedance shall be greater than 100K ohms, and shall be resistive in nature for all inputs except Synchros. For synchro inputs the Scott-T transformers shall have a minimum input impedance of 20K.

Common-Mode Voltage

Input signals shall be differentially received and retain specified accuracies with $\pm$5VDC or 5VRMS at 400Hz common-mode voltage applied.

Output Range

The output voltage will be chosen to be compatible with the analog multiplexer and A/D converter utilized.

Filter Requirements

The filter defined above following the synchronous demodulator will provide the desired filtering for the AC and synchro signals. The DC signals and all the potentiometers, except three of the Type III, shall have a single-pole low-pass filter provided, whose 3-db point is adjustable from 1.0Hz to 100Hz $\pm$50% by selection of appropriate resistors and capacitors. Three of the Type III signals require special filtering because of specific bandwidth response requirements of impact accelerometer channels.

Three Butterworth filters with 3-db points at 180Hz ±10% shall be provided with a minimum of 30-db rejection at 600Hz and higher in frequency.

Accuracy

The RSS summation of all errors due to manufacturing tolerances of components, offsets, temperature effects, common-mode voltages, etc., shall represent less than ±2% F.S. error.

Frequency Inputs

Signal Types, Ranges and Quantities

Five ranges of frequency are to be covered as given below. A maximum of three frequency inputs will be provided: the 7-90Hz input shall be an approximate sine wave, the rest can be sine waves, square waves, or pulses with a minimum pulse duration of 10 microseconds. Input peak amplitude shall be between 0.5V and 70V. Three inputs shall be accommodated. Frequency ranges are:

7 - 90 Hz

160 - 400 Hz

500 - 1500 Hz

250 - 3000 Hz

5000 - 13,000 Hz

Conditioner Requirements

Input Impedance

The input impedance shall be greater than 100K ohms and shall be resistive in nature.

Common-Mode Voltage

Input signals shall be differentially received and retain specified accuracies with ±5VDC or 5VRMS at 400 Hz common-mode voltage applied.

Output Range*

The frequency shall be converted to an equivalent DC voltage compatible with the analog multiplexer and A/D converter utilized.

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* Alternatively, conversion can be from frequency to digital, in which case these paragraphs do not apply.

Filter Requirement*

Filtering shall be provided to reduce any residual ripple to less than 1% full scale error. The filter lag shall be no lower than the equivalent of a single-pole low-pass filter with a 3-db point at one Hz.

Accuracy*

The signal conditioner shall generate an output voltage that is approximately linear with frequency. The repeatability of the signal from a specified response (common for all units and frequency types) shall be as specified below. The repeatability error includes an RSS summation of all error sources due to manufacturing tolerances of components, offsets, common-mode voltages, and temperature effects.

80% - 100	$\pm$2% of point
80% - low limit	$\pm$10% of point

Discrete Inputs

Signal Type Ranges, and Quantities

Two types of discrete (logic zero/logic one) inputs shall be accepted as defined below. Twenty-two discrete signals shall be accommodated.

I	Greater than 100K ohms	Less than 375 ohms
II	Greater than 18.5VDC	Less than 1.9VDC

Conditioner Requirements

Single-Ended Receiver

The discretes shall be received single-ended, and referenced to a common 28V power return bus.

Filter Requirements

An input filter shall be provided for all discrete inputs consisting of a low-pass filter with a single pole at 30 Hz $\pm$50%.

Input Impedance

The input impedance shall be greater than 100K-ohms and resistive in nature.

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* Alternatively, conversion can be from frequency to digital, in which case these paragraphs do not apply.

Output Range

The output voltage shall be compatible with the discrete multiplexer provided.

Computer Data Input

Analog Multiplexing/A/D

Twenty-four channels of analog multiplexing shall be provided which are compatible with the outputs of the signal conditioners.

The output of the multiplexer shall be digitized by an eight-bit A/D converter. The A/D conversion time shall be 20 msec, maximum. Addressing of the multiplexer shall be random in nature, under microprocessor control. The A/D converter shall provide an "A/D-complete" signal. The accuracy from analog multiplexer input to A/D digital output shall be $\pm 1\%$ of the input signal. This error shall include all sources of error including manufacturing tolerances temperature effects, off-sets, channel cross talk, etc.

Discrete Multiplexer

A discrete multiplexer shall be provided that is capable of accepting 24 (22 plus 2 spares) discrete input signals from the discrete signal conditioners defined herein. The discrete multiplexer shall be randomly addressable under microprocessor program control.

Microprocessor and Support Circuitry

Microprocessor

A microprocessor shall be provided to accomplish the tasks outlined in paragraph 7.3. It should have the computational capabilities and the speed of the Intel 8080 or 8085 microprocessors, as a minimum.

Clock

A clock shall be provided with countdown circuitry as required for microprocessor operation and I/O control.

Data/Control Bus Drivers

Data/Control Bus latches and drivers will be provided as required for proper operation of the microprocessor and proper I/O control.

I/O Interface

The appropriate computer I/O control logic shall be provided to interface with the input signals, and provide the output signals as well as multiplexer control signals.

RAM

A scratchpad memory with 256 words of random access memory (RAM) shall be provided.

ROM

Two thousand words of read only memory (ROM) shall be provided for program storage.

EAROM

Thirty-two thousand words of Electrically Alterable Read Only Memory shall be provided for nonvolatile data storage. EAROM Read/Write control and power strobing must be available under processor control to minimize EAROM power dissipation.

Watchdog Timer

A watchdog timer, reset under processor control, shall be provided. Its output shall cause the Bite output to activate directly.

Data Output

The following outputs shall be provided.

EAROM Readout

A two-wire RS232-compatible input and output shall be provided so that via an input discrete, the data stored in the EAROM will be read out sequentially from a given starting address to an external Portable Ground Unit (PGU). The RS232 input shall be used for handshaking functions in conjunction with the PGU and data readback to verify proper EAROM transcription.

Bite Output

A magnetic latching indicator shall be provided to indicate a unit failure. The indicator shall be tripped by the microprocessor based on software diagnostics, or, directly by the watchdog timer. The indicator is excited directly by 28VDC, and represents a 50ma current load. In addition, a discrete drive shall be provided for remote annunciation.

Read Data Output

A magnetic latching indicator shall also be provided to indicate the occurrence of an unusual event. The data should then be dumped using the PGU. The indicator is tripped by the microprocessor. The indicator is again excited by 28VDC and represents a 50ma current load. (Same as above notes.)

Maintenance Readout Unit Output

An output interface shall be provided to allow a Burroughs Self-Scan Display or equivalent to be driven by the real-time data under microprocessor control. To minimize the memory overhead carried in the unit for read-out, as well as any special interface, the memory required will be external to the AIRS. The essential data and control busses will be provided, and adequately buffered, to prevent the introduction of noise into the unit. In addition, five discretes shall be input to the discrete signal conditioners to allow parameter identification for the maintenance read out.

Bite Signals

An input signal equivalent to a mid-range analog signal shall be provided. Two discretes shall also be provided, one wired as a "1", and one as a "0".

Power Supply

A regulated power supply shall be provided which is energized from the 28VDC aircraft bus per MIL-STD-704D, as modified herein. The power supply shall provide the necessary excitation for the AIRS internal circuitry plus the following output for sensor excitation: Voltage $\pm$10VDC at 50 ma/side with a tolerance of $\pm$1%.

Data Stop Signal

A DC power bus signal through any cockpit switch that is turned for start conditions shall be provided to close a set of contacts to connect the AIRS unit to the 28 Volt battery. After energization, the AIRS unit shall generate a closure of a second set of contacts whenever the rotor speed output is greater than one pulse per second. This second set of contacts shall open when rotor speed falls to less than one pulse per second for 1 to 3 minutes (adjustable by resistor change). Figure 49 represents the above contacts as implemented in relay logic. Solid-state devices should be utilized, provided their "off" impedance is greater than one megohm. The logic is summarized below:

CONDITION	LOGIC
Unit initially energized	DC power bus is Hi-signal via any external switch that is turned on during APU and engine start.

Unit remains energized	DC power bus Hi + NR >1 pulse/sec
Unit becomes de-energized	DC power bus low. NR <1 pulse/sec For 1-3 minutes (adjustable)

AIRS Airborne Electronics Unit Mechanical Concept

Further Survivability Considerations

Sections 4.8 (Crash Protection Rationale) and 6.3 (Results of trade-off studies) describe in detail the requirements and methods for implementing survivable electronics, in terms of operation and data retention under crash conditions. Phase II examined the recommended data module survivability concept further and validated the concept as determined in Phase I. In addition, further study was undertaken in three areas. They are:

(1) Impact Survivability of the total AIRS package in terms of operation through 150g 10-millisecond impacts. In addition, survivability of the system elements from an aircraft installation point of view was studied with an airframe manufacturer and is reported in section 7.6.

(2) Successful data retention while being immersed in salt water for up to four weeks.

(3) Use of intumescent coatings to increase thermal survivability.

These three areas are discussed further below as a part of the mechanical concept description.

The AIRS airborne electronics unit concept is illustrated in Figure 50. The construction utilizes well established methods of military airborne packaging of electronics. In addition, special attention is paid to operational integrity through 150g, 10-millisecond shocks, so that impact accelerations can be measured and stored by the system. The packaging concept also utilizes techniques which maximize automated assembly methods and reduces labor content to a minimum in order that recurring cost is kept low.

The package would consist of four major modules, all connected to a multilayer master interconnect board (MIB) as shown. One module would form the end assembly containing the two external connectors, the latching indicators, the protected memory submodule, and the heavier power supply magnetics. This module would be connected to the MIB using flextape wiring. All modules would be rigidly connected to the MIB with the entire subassembly positioned inside a sheet metal can having one open end. All modules would be securely fastened to the housing via threaded screws as shown. The entire unit would be fastened to the floor of the aircraft in a rigid mount. The package is rigidly fastened together as described to insure operation through the 150g 10-millisecond impact accelerations in any axis. This is done at the expense of a lower level of repairability. However, since the package is predicted to have a mean time between failures of 10,000 hours unit teardown should be very infrequent. The board sizes and rigid mounting would typically yield

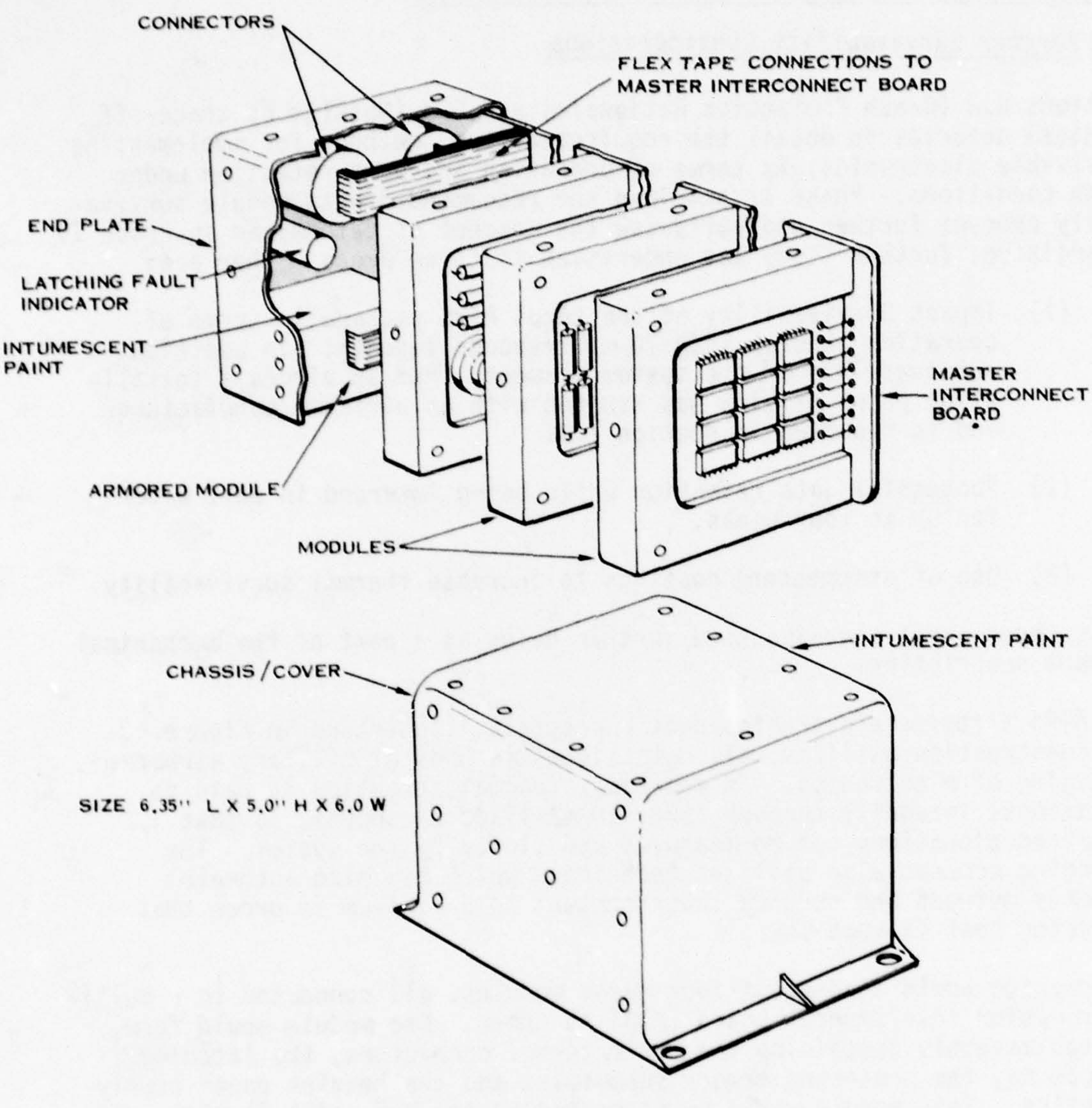


FIGURE 50. AIRS PACKAGE CONCEPT

structural resonances in the 150-Hz and above range. Units consisting of similar size subassemblies routinely pass vibration levels in excess of 150g's at frequencies with half periods equivalent to the 150g ten-millisecond impact design objectives.

Heat transfer during normal operation will be via metal conducting paths on the module printed circuit cards to the module frames. Each module other than the end cap subassembly would contain two multilayer printed circuit boards with components mounted on each side. Heat would be conducted from the frames to the outer case. Heat would be transferred to the ambient air via free convection and radiation. Some heat would also be transferred through the mounting base to the floor. The unit would be drip proof but nonhermetically sealed.

The armored module would be located on the base edge of the end plate. The internal protected module construction is explained in detail in sections 4.8 and 6.3. Thermal Survivability of data within the protected module is provided using a water boil-off technique using layers of water-soaked material around an inner armored can containing the EAROM chips in a hybrid hermetically sealed configuration. Since the EAROMS themselves are hermetically protected immersion in salt water of the memory module for periods in excess of 4 weeks should not be a problem. The exposed outer faces of the protected memory module would be coated with an intumescent coating as shown on Figure 51. The protection process of an intumescent coating starts with the surface expanding, causing a charred zone. Expansion processes will continue as long as an active resin remains in contact with the protected material. The charred region will expand 80 to 175 times the dry film thickness of the material. The charring regions are activated in three seconds at a temperature of 560°F. The thermal conductivity of the charred zone is low (K=0.11 Btu/hr-ft-°F). The high oxidation resistance of the polymeric char, combined with the low thermal conductivity, creates an environment in which much of the incident heat loss is reradiated. This effect minimizes the flame exposure to the module and provides a barrier that will decrease the heat flux input to the module.

The ability of the EAROM chips in a hybrid configuration in the protected module to take 1000g shocks is predicted by previous test work in the industry on electronic components. Integrated circuits have been successfully tested to 3000g 4-millisecond 1/2 sine levels (three blows in each axis) without failure. Other components such as transistors, diodes and resistors have met similar requirements at 2000g's.

Electronics Unit Size and Weight

A revised size and weight estimate was prepared using a detailed electrical and mechanical parts list as generated in Phase II.

The size and weight prediction is based on using contemporary component technology and extrapolating reductions in size and area to the 1980 period. No hybridizing was assumed for any electronic components other

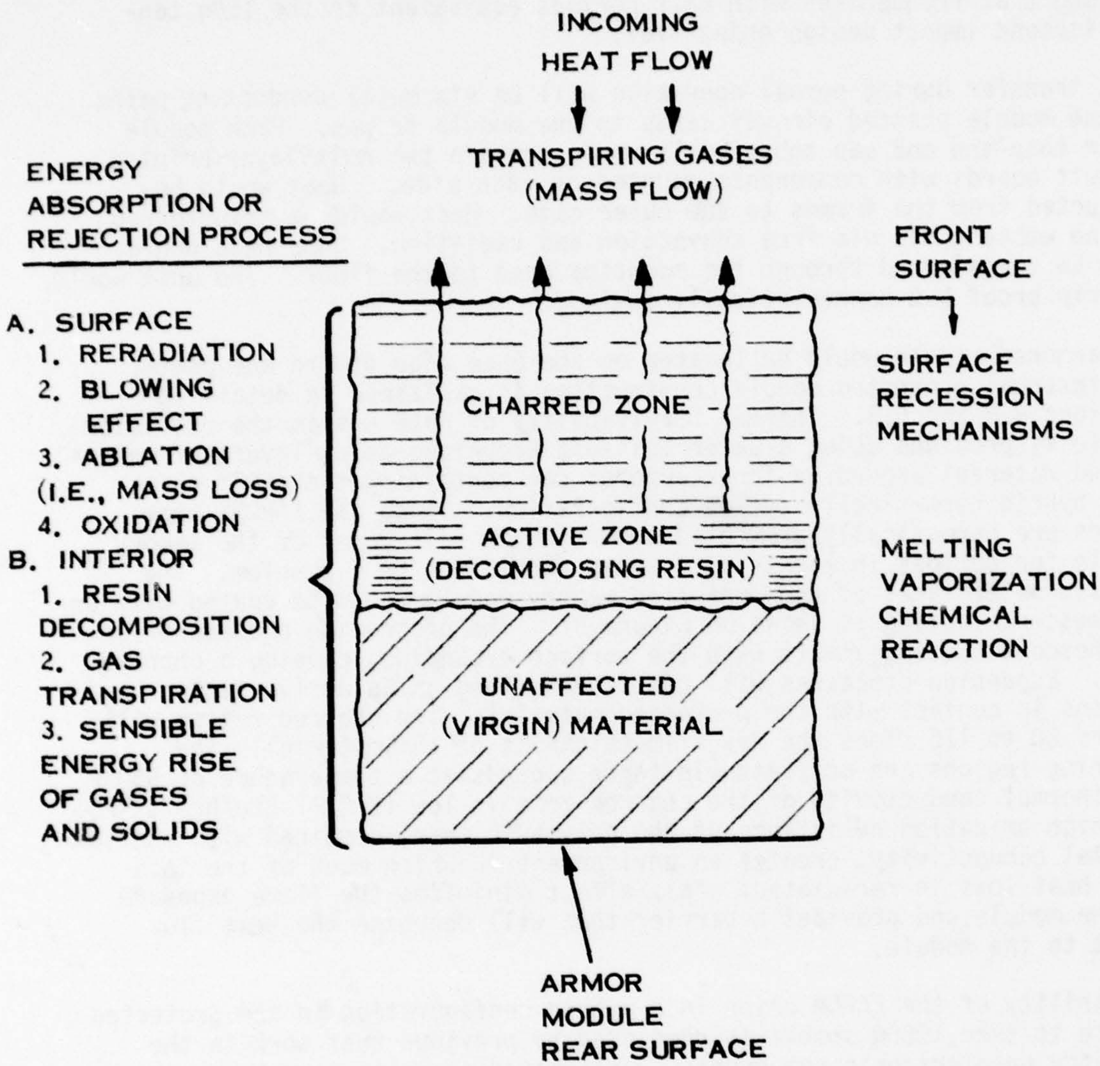


FIGURE 51. GENERAL ABLATIVE MODEL FOR CHARRING MATERIAL

than the protected memory circuits. Only components currently available from industry were used to compute board area and unit volume requirements with extrapolations made from that point. Hybridizing (i.e., custom interconnection and packaging of components) will afford further reductions in size and weight, but it will tend to drive unit cost up; hence it was not assumed.

The extrapolation used to predict further decreases in component area requirements comes directly from experience in the design of electronics using similar technology over the last three years. See Figure 52.

A digital electronic control went through three design iterations where the functional requirements remained essentially constant, but advantage was taken in available component integration as the designs progressed. Area requirements by experience went down 15% per year. It is expected that the trend will continue at a somewhat lower rate with 10% per year probable. The printed circuit board area was estimated to be 91 square inches, which required six printed boards in a chassis size of 6.35 by 5.0 by 6.0 inches.

The volume is 190.5 cubic inches.

The package weight was estimated to be as follows:

Raw electrical Components	-	2.64 Pounds
Mechanical Components	-	2.48 Pounds
Protected Memory Module	-	2.50 Pounds
Total		7.62 Pounds

It should be noted that the weight estimated in Phase I increased overall while the memory module weight remained essentially the same.

AIRS Sensors

Section 4.1 discusses those signals that are available from sensors currently existing on the four airframes studied. Section 4.2 discusses in detail those sensors that should be added to make up the recommended signal list. This section provides further detail on AIRS Sensors that should be added to the new aircraft studied.

The AIRS unique sensors consist of the following:

* Impact accelerometer triaxial assembly
* Vertical flight g accelerometer
* Vernier altitude transducer
* Control position transducer

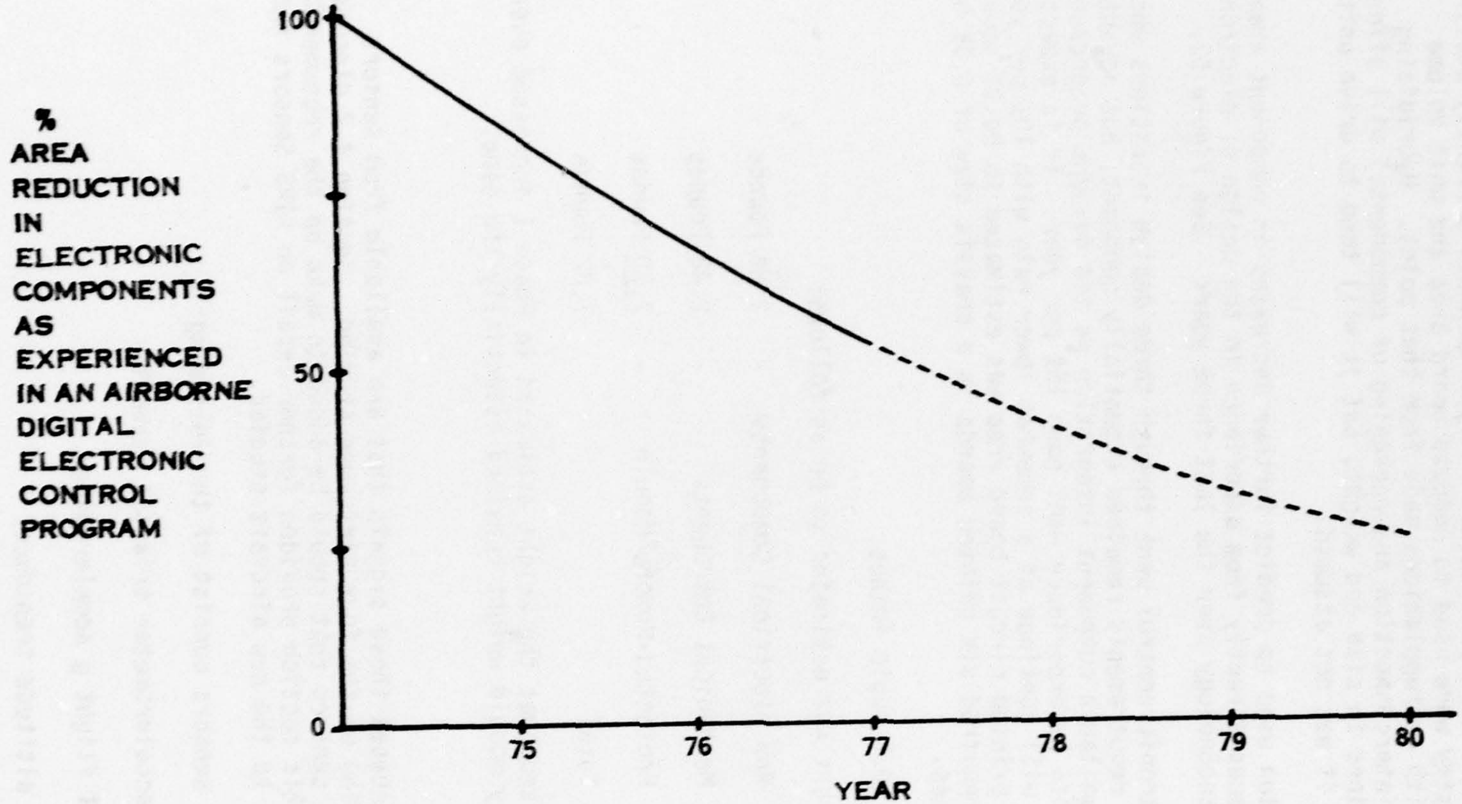


FIGURE 52. ELECTRONIC COMPONENTS DENSITY TREND

The requirements for AIRS unique signals in terms of accuracy, repeatability, low size, weight and cost appear to be achievable with existing technology. The only area where some question remains is life.

Sensor Life

The Army requirement for a 5,000-hour life can readily be met with the electronics portions of the system. However, imposition of this requirement on sensors may be unrealistic and difficult to test and assess for compliance. Sensors employing potentiometric pick-offs are generally rated in terms of number of operating cycles. In an environment where noise or legitimate high-frequency inputs are present within the bandwidth of the device, the number of cycles per unit time which result in wearout could be large and therefore, life limiting. In the case of pressure transducers, adequate pneumatic damping can limit input cycles to those which generally describe the flight of the aircraft. Piezoresistive type devices are available which are small and low in cost. These devices can operate for millions of life cycles and hence can meet the life criteria for AIRS.

The miniature impact measuring accelerometers utilize DC pot pick-offs. Since the range is ±150 g's, the normal flight environment in most cases will not move the devices out of the stiction band with the exception of the vertical axis. However, the cycles in this axis would be representative of a number of landings and occasional flight g levels great enough to take the sensor out of the stiction band. Potentiometers are typically capable of 10^6 operating cycles. Hence, the impact measuring devices appear to also meet the AIRS life criteria.

The sensors that will be normally subjected to a higher frequency operational environment are the vertical flight g accelerometer and the control position pick-offs. Both the AAH and the UTTAS aircraft are using potentiometer control position pick-offs as an operational part of the flight control system. The airframe manufacturers have the confidence that current potentiometer designs can meet extented life criteria. It appears reasonable therefore to utilize similar devices when they need to be added for AIRS such as the lateral cyclic and pedal position pick-offs for the UTTAS application. The vertical flight g pick-off appears to be the remaining device, which warrents further study. The number of cycles experienced in one years operation would be of the same order as the sensors cycle design life. It would be sound practice that data be extracted on an annual basis from each aircraft's AIRS unit and routinely examined in a ground-based computer program. A potentiometer exhibiting wear out could be discerned by an increasing or very low average data rate for the particular signal. This routine suggests that sensors that are connected to AIRS which are part of other systems could also be examined via the AIRS data readout.

Accelerometers

Subminiature accelerometers that provide adequate performance in a very small package are available. These are low cost seismic mass devices

using resistive pick-offs that can be triaxially mounted for installation in the aircraft.

The characteristics of a typical cluster are given below. See Figure 53.

* Each Accelerometer
  * Edcliff subminiature model 7-101 or equivalent

    Impacts ±150 g's

    Vertical Flight ±5 g's
  * Size: 1.25 X 1.25 X 0.78 inches
  * Weight: 1.5 oz
* Triaxial Mount w/Vertical Flight Accelerometer
  * Electrical Connection - block connector
  * Overall maximum dimensions - 2.75 X 2.75 X 4.75 inches (combined unit)
  * Weight (combined unit) - 1.0 lbs.
  * ± 10 VDC Excitation from AIRS

<u>Pressure Altitude Sensor</u>

Altitude sensors are available with sufficient linearity and resolution in a physically small package and low cost for use in the AIRS for altitude interpolation between the digital reporting altimeter output. One class of devices which appears useable is piezoresistive diaphragm units employing a four-arm active bridge with DC excitation from an external source.

Figure 54 includes the important characteristics of such a device.

<u>Control Position Pickoff Potentiometers</u>

Rotary potentiometers using composition material are available which provide adequate control position information at low cost and weight. The pots can be installed and linked to the control linkage as shown in Figure 66.

The essential features of the potentiometers are as follows:

* 5K ohm
* 1% of full-scale accuracy
* ± 10 VDC excitation
* 0.1 lbs.
* Rotary Input - max rotation less than 90 degrees

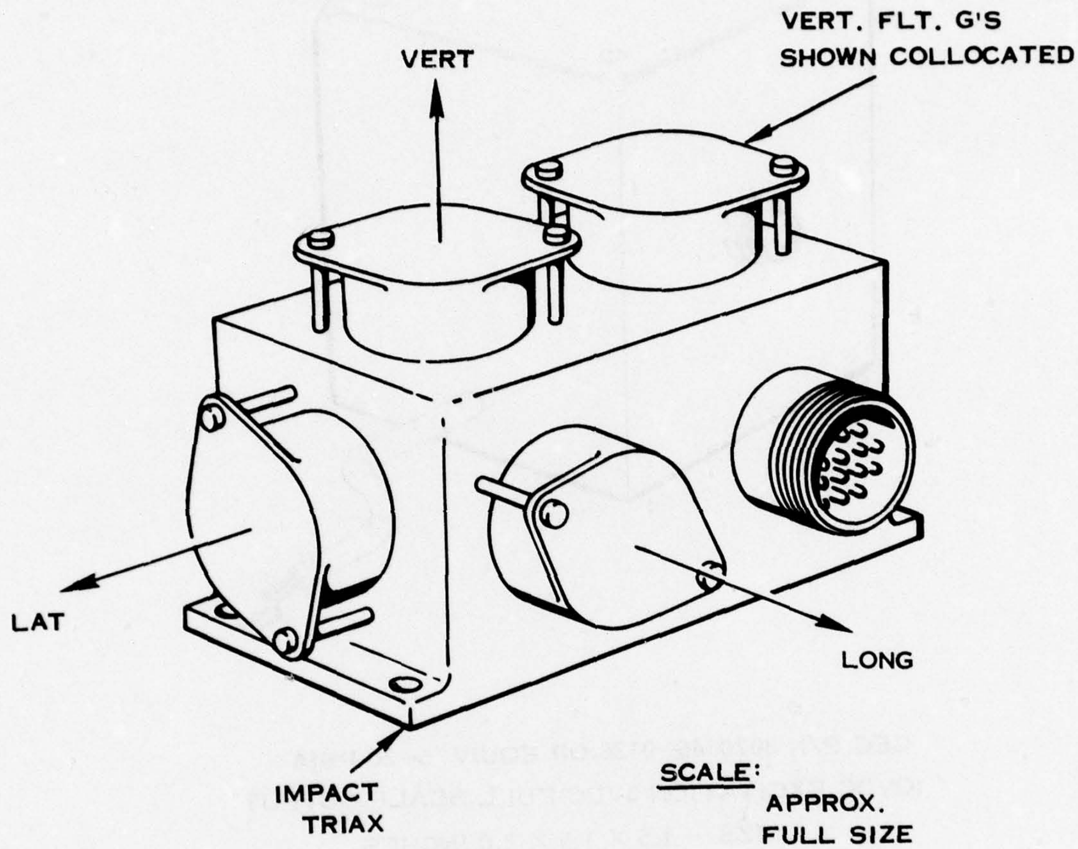
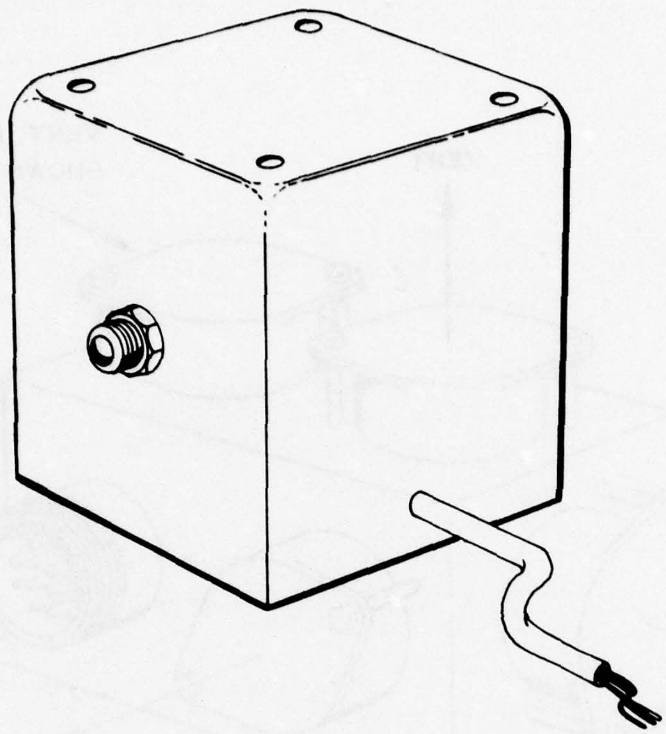


FIGURE 53. AIRS ACCELEROMETERS



CEC P/N 3670646–0136 OR EQUIV 5–20 PSIA
IOVDC EXCITATION 5VDC FULL SCALE OUTPUT
SIZE – 1.5 X 1.5 X 2.0 INCHES
WEIGHT – 0.75 LBS.
PRESS POINT 1/8'' NPT PIGTAIL CONNECTION

FIGURE 54. PRESSURE ALTITUDE SENSOR

7.3 AIRBORNE SOFTWARE PROGRAM

The major functional operation of the AIRS is performed by the microprocessor under software control. This program would be stored in a PROM or ROM. The following paragraphs elaborate upon the software tasks and amplify the definition of the total AIRS system.

Data Control and Compression

The input signals are read into the memory via a program control. Tentatively, it is planned that all inputs be sampled once per second, except for vertical, lateral, and longitudinal impact accelerations. These are sampled at 600 Hz. The frequency signals must be timed by an interval timer to convert them to a digital number proportional to frequency.

Synchro inputs are presented as digital numbers proportional to the sine and cosine of the angle. A software arc tangent routine would be utilized to convert these inputs to 8 bits corresponding to the angle.

All inputs are then compared against a floating limit, except for accelerations. If during a 1-second interval, one or more input parameters exceed their floating limit, an output message is generated. This message consists of a time code, the number of words in the message, word identifier(s), plus data, as outlined in paragraph 4.7.

For the case of vertical flight g accelerations, each sampled value is compared against a fixed limit. Should that limit be exceeded, successive values of acceleration are examined, and the peak value that occurs prior to the acceleration again passing below its limit, together with the time interval which it remains above this limit, is stored. An output message format is again provided consisting of a message identifier, a parameter identifier, and elapsed time in 1/4 sec. increments, plus the peak acceleration and time over limit. For impact acceleration measurements, the complete profile is stored at a 600 Hz sampling interval when fixed limits are exceeded. This will only occur under accident conditions.

Should no limit exceedances occur, once each minute the present state of all parameters is outputted in a fixed data frame preceded by two synch words.

The writing of the data into an EAROM is under program control. This control includes raising proper control lines to write data, erase previous data, and read after write verify. Timing sequencing is done utilizing the programmable interval timer which is part of the microprocessor I/O.

New data should no longer be stored when it is of no value (i.e., aircraft sitting on ground with engines off). Therefore, certain parameters are monitored to provide an inhibit on data storage. It is presently envisioned that if main rotor speed falls below (Y) RPM, recording will be stopped after a suitable delay time.

It may be desirable to stop writing in a given predetermined portion of the memory to insure preservation of some data. This is in recognition of the possibility of an in-flight event worthy of recording followed by a significant period of time before landing and rotor wind down.

This is handled with very little operational software overhead if an event button located in the cockpit is depressed after manually recognizing an event important enough for permanent storage. Selected automatic permanent data retention in part of the memory can also be implemented with or in place of manual means. For example, for a two-engine aircraft if one engine torque goes to near zero, automatic permanent storage could be initiated. A part of the data memory would always be retained for recording subsequent data.

Since the inputting of data, limit checking, and outputting of data is all under program control, maximum flexibility exists for changes as required. For example, certain parameter(s) should be looked at more frequently to ensure proper data fidelity. This can be accomplished by changing the two DIP's which contain the old program with two new DIP's with the new program.

Bookkeeping Functions

The processor will provide all necessary bookeeping functions involved with the AIRS. Two major ones involve computing elapsed time and keeping track of where in the memory to write the next data message. Since power shutdowns or power outages will occur, an orderly shutdown/start-up procedure is utilized to ensure the integrity of the data for later analysis.

Elapsed time is maintained contiguous after power interrupt and resets only when all elapsed time bits are 1's.

This should prevent any time ambiguity in the data. The last address written in is also stored so that useful data is never written over after a power outage.

Built-In Test Software

An extremely comprehensive BIT program is utilized. It is patterned after other similar digital systems manufactured by Hamilton Standard which have demonstrated a high degree of coverage of BIT (typically 95% coverage). The following paragraphs describe the BIT software.

Analog, discrete, and frequency test signals are internally generated. Once each second the outputs of the A/D or signal conditioners are examined and the BIT signal is compared against software limits which represent its proper value.

EAROM memory is read after writing to verify proper operation. ROM or PROM contents are periodically summed and checked against a stored sum value. RAM is periodically checked in segments to verify that it can be written into and read from accurately.

A test program which utilizes all computer instructions is performed periodically and the answer compared to a stored value for accuracy.

Input signals are scaled to work well within the dynamic ranges of the signal conditioning amplifiers and A/D converter. Out-of-range input signal values will then be recognized as failures of the input device.

Noncredible rates of change of inputs will also be sensed, applied against limits in software and flagged by the BIT indicator. Certain inputs that can be correlated will have appropriate routines (fine and course altitude is a candidate) to verify data credibility. Finally, a hardware watchdog timer is provided which must be periodically reset by software to prevent it from timing out and activating the BIT indicator. This circuit will detect any program hangups.

Portable Ground Unit Interface

Discrete input recognition is provided to initiate data dump from the airborne system. On recognition, the stored program controls the dump to an external cassette unit by means of a RS232 compatible interface.

Maintenance Parameter Readout Software

The software will recognize a discrete input that indicates a parameter readout mode. The software will decode five additional discrete inputs, fetch the particular parameter and output through a special interface. The memory for decoding and outputting in engineering units to an external display will be external to the AIRS unit.

Detail Airborne Unit Software Guidelines

Data Input

The control of the analog multiplexer, discrete multiplexer, and the digitization of analog data shall be provided by a software program. All data shall be inputted once per second except three of the type-III signals that represent the three axis impact acceleration data. These signals shall be inputted 600 times per second.

Synchro Conversion

The three type-II signals are synchro inputs, and two values are presented for each input, one representing sin θ, the other cos θ. An arc tangent routine should be utilized to convert these inputs into θ, so that one eight-bit word will represent the value of θ in radians or degrees.

Elapsed Time

Elapsed time in minutes shall be kept by a software clock. This time should be continuous, and reset only by an all "1"'s condition. Precautions taken to ensure that this occurs with power turn on/off are covered further on. Two subminute timer intervals are required, one with 6 bits, where each bit represents 1 second for floating limit time coding for all parameters except acceleration; and one with 8 bits, where each bit represents 1/4 second for fixed limit time coding for acceleration. These subminute timers shall be reset each minute, and reset with power turn on.

Data Compression

Floating Limits

A floating limit check is applied to all analog parameters except the four acceleration inputs. The parameters are listed in Table 39 and are represented with binary I.D. numbers. When a floating limit is exceeded, a new boundary is established around the new value for subsequent checks, and the data output routine is notified of the exceedance.

Impact g's

The three values of impact g's are compared against fixed limits. When the limit is exceeded, the four values prior to the limit exceedance, the values during limit exceedance, and the four values after limit exceedance shall be buffered up to a maximum of 32 words. The data output routine is notified of the exceedance, reference paragraph 9.6. Since this signal is bidirectional, a + and - limit is required and the exceedance (+ or -) must be identified.

Flight Vertical g's

The flight g's shall be compared against a fixed limit. When the limit is exceeded, the data shall be monitored for peak value and duration above the limit. The data output routine is again notified of the exceedance. Since this signal is bidirectional, a + and - limit applies, and the exceedance must be identified as such.

Engine Torque Key

If an engine torque falls to less than a given lower limit, notify output data routine.

Data Output

A data output program shall be provided to format the output data, and the data shall be stored in appropriate address locations in the EAROM. The following paragraphs elaborate on this data.

Fixed-Frame Output

Once each minute a complete data frame is outputted, consisting of the 26 words shown in Table 39. The first two words are allocated for a synchronization bit pattern. Word identification is via word sequence. Word number 7 represents the 8 LSB of the altitude grey code, the MSB is packed into Discrete word No. 1 (parameter 19).

Variable Frame Output

Whenever a floating or fixed limit is exceeded, an output data message is provided. Six basic types of messages exist. The first four are associated with floating limits and represent single, double, triple, or quad time concurrent limit exceedances. The message formats are shown in Figure 55. The first byte of the message is used for time and number of exceedance data. Six bits represent time to within 1 second each minute, and two bits represent the number of exceedances in binary notation. The next byte is used for parameter I.D. Four bits are required, reference Table 39, so each byte can identify two parameters. The next bytes are used for parameter value. If more than two exceedances occurred, the message is appended with an added byte for parameter ID's plus parameter value bytes as shown in the referenced figure. The last two message formats are applicable to acceleration inputs. Figure 56 illustrates these cases. For impact G's six "0" start the message, followed by two bits representing one of the four acceleration inputs. The next byte identifies the time of occurrence within 1/4 second. The next byte identifies the polarity of the impact, and the number of words in the message. Finally, the message is terminated with 4 to 32 bytes of actual data. For flight vertical G's, the initial two bytes are the same; however, the message is completed with two bytes, one representing sign and peak magnitude, and the other representing time over limit, with 1/4 second granularity.

EAROM Control

To minimize heating in the protected memory, the EAROM is normally depowered by the processor unless being written into or read from. A 16-word buffer memory should be used to store output data as described above in a temporary fashion until it is loaded into EAROM using the following sequence if rotor speed has not fallen to near 0. Note, appropriate software delays will be required between steps.

1. Enable EAROM power.
2. Read contents of location 0; erase data of location 0.
3. Erase data at the address in location 0.
4. Write first word of buffer memory into the location read from location 0.
5. Read back data and verify if proper; if not, repeat 3, 4, and 5 up to 6 times. If unable to write, activate BIT output and go to next step.
6. Increment address by 1.
7. Erase data at this address.
8. Write next word of buffer memory into this location.

TABLE 39. BASIC FIXED-FRAME FORMAT

WORD (8 BIT)	PARAMETER	PARAMETER I.D.
1	Synchronization	NA
2	Synchronization	NA
3	Time (Minutes)	NA
4	Time (Seconds)	NA
5	Airspeed	0001
6	Heading	0010
7	Altitude (Code)	NA
8	Altitude (Transducer)	0011
9	Vertical Acceleration (Impact)	NA
10	Longitudinal Acceleration (Impact)	NA
11	Lateral Acceleration (Impact)	NA
12	Pitch	0100
13	Roll	0101
14	Engine Torque No. 1	0110
15	Engine Torque No. 2	0111
16	Rotor RPM No. 1	1000
17	Engine RPM No. 1	1001
18	Engine RPM No. 2	1010
19	Discrete Word No. 1	NA
	Chip Detector (4)	
	Fire Detector (2)	
	Most Significant Altitude Bit	
	Spare	
20	Discrete Word No. 2	NA
	Hydraulic Pressure (3)	
	Spare (3)	
21	Longitudinal Cyclic Position	1011
22	Lateral Cyclic Position	1100
23	Collective Position	1101
24	Yaw Pedal Position	1110
25	Radio Altitude	1111
26	Flight Vertical G's	NA

SEC	00	ID#1	0000	PARA # 1

1 PARAMETER 24 BITS

SEC	01	ID # 1	ID#2	PARA # 1	PARA # 2

2 PARAMETERS 32 BITS

SEC	10	ID # 1	ID # 2	PARA # 1	PARA # 2	ID # 3	0000	PARA # 3

3 PARAMETERS 48 BITS

SEC	11	ID#1	ID # 2	PARA # 1	PARA # 2	ID # 3	ID#4	PARA # 3	PARA # 4

4 PARAMETERS 56 BITS

FIGURE 55. MESSAGE FORMATS

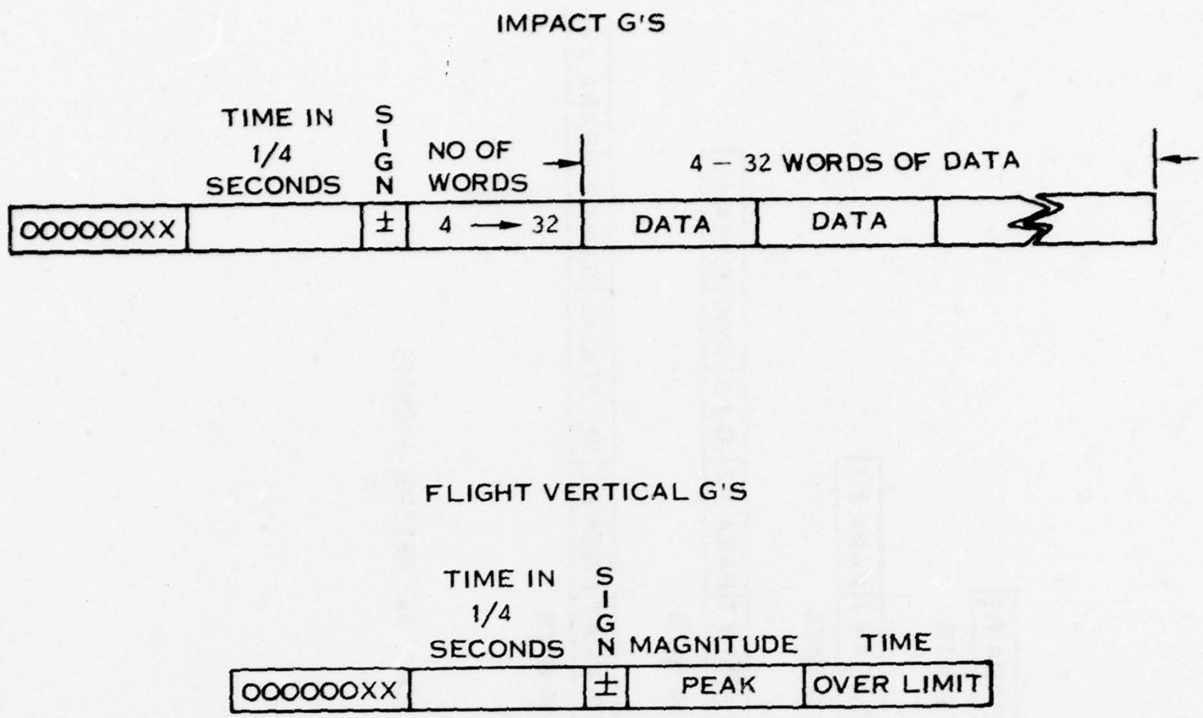


FIGURE 56. ACCELERATION INPUT MESSAGE FORMAT

9. Read back data and verify if proper; if not, repeat steps 7, 8 and 9 up to 6 times. If unable to write, activate BIT output and go to next step.
10. Repeat steps 7-9 until last word of buffer memory is written.
11. Increment address by 1.
12. Store the value of address in location 0.
13. Disable EAROM power.

The above incrementing will continue through location 3583 and reset to 2. If an engine torque has fallen to zero, the data is written in a protected section of memory from location 3584 to 4096 and the Data Read Output is raised. Additionally, the 256 words prior to a torque falling to zero are transferred from their normal storage area per above sequence to this special section of the memory. The subsequent 256 words of data are stored in the remaining bytes of memory. The above routine for data transfer then resumes. In the event that the torque should again fall to zero on the same engine, the above data will be overwritten. If the torque on the second engine falls to zero, it will not be overwritten, unless the data has been dumped into the PGU (Portable Ground Unit).

Power Turn Off/On

An orderly power up/down sequence is vital to ensure proper recovery of the data. The following sequence should be followed.

Power Loss

The 16-word buffer memory shall be dumped into EAROM if it consists of limit exceedance data, but frame dumps in the process of being made can be terminated at a byte boundary. The present elapsed time in minutes shall be stored in location 1 in EAROM.

Power Turn On

The elapsed time in minutes shall be read from EAROM location 1. The "seconds" elapsed times shall be reset to zero. A fixed data frame shall be outputted, with one of the spare discrete bits set to a "1" to indicate a power outage, utilizing the EAROM output routine.

BIT

The following software BIT checks shall be made:

a. Analog BIT Input compared to stored value within $\pm$ X counts.
b. Discrete "BIT Inputs" checked against stored values.
c. EAROM read after write verify.
d. ROM or PROM summed periodically and compared against stored value.
e. RAM checked in segments sequentially.
f. Dummy program run to check instruction execution.
g. Inputs checked for noncredible limits.
h. Inputs checked for noncredible change in value over sampling interval.
i. Correlation made between grey code altitude and altitude transducer.
j. A watchdog timer should be reset once per second to verify proper program performance.

Portable Ground Unit Readout Software

Discrete input recognition is provided to initiate data dump from the airborne system. On recognition, the stored program controls the dump to an external cassette unit by means of an RS232 compatible interface. Typically, the sequence of events would be:

Step 1. The AIRS unit computer commands the external tape unit to rewind to beginning of tape via appropriate control character over RS232 interface.

Step 2. The recorder will notify the processor when this has been accomplished.

Step 3. The computer will command the recorder to advance to Load Point.

Step 4. The recorder will notify the processor when this has been accomplished.

Step 5. The processor will then start at the last recorded address plus one, and sequentially dump all the contents of the memory to the tape unit.

Step 6. The processor will command the recorder back to the Load Point.

Step 7. The recorder will notify the processor when this has been accomplished.

Step 8. The processor will then place the recorder in read mode, and compare contents of the recorder with the internal memory.

Step 9. Should any more than (TBD) bit errors occur, Steps 1-8 will be repeated.

Step 10. If less than (TBD) bit errors occur, the transcription is correct and Steps 1 and 2 will be repeated.

Step 11. The "transcription complete" output will then be annunciated on the PGU by appropriate control code.

Maintenance Parameter Readout

The memory required for the output shall be provided externally to the AIRS unit. The program shall provide the following functions:

a. Decode the five discrete inputs to identify the desired output.

b. Present the output as ASCII characters. Four characters shall be alpha numeric for parameter identification for up to 26 parameters. Four numeric characters will be provided for value. Value should be in engineering units. It is assumed that parameters can be characterized with sufficient accuracy with a straight line input/output relationship (i.e., Y=MX + b).

7.4 PORTABLE GROUND UNIT (PGU) DESCRIPTION

With the microprocessor in AIRS available for additional tasks, the Portable Ground Unit for data transferral can be a very simple unit. RS232-compatible Phillips cassette recorder units are available which respond to commands generated by an external computer (i.e., rewind, advance to load point, record, read, etc.) and record and replay data. Such a unit could be plugged into the AIRS aircraft unit and generate a memory dump command. The microprocessor, via a stored program, would then command the recorder in an appropriate fashion to allow recording and replaying of the data for verification of accurate transcription. This is accomplished over the serial full duplex RS232 interface provided within the AIRS airborne unit. When transcription is complete, the microprocessor would annunciate it via the transcription complete output to the Portable Ground Unit. A set of guidelines for a PGU follows along with a description of an available unit.

System Design Guidelines for the AIRS Portable Ground Unit

Scope

This document shall define the input, output and performance requirements for a portable ground unit (PGU) that shall be part of the ground based equipment for the Accident Information Retrieval System (AIRS)

The principal function of the (PGU) shall be to record and transmit data obtained from the AIRS airborne unit as required. This function shall normally be performed only after an incident requiring investigation. The data shall be transferred to a tape cassette or other medium contained in the PGU for transportation or transfer via a modem over the telephone lines to a centrally located Army computer for analysis.

Applicable Documents

TBD

NOTE: Several manufacturers currently build devices which can satisfy PGU operational requirements. These existing devices are designed for varying degrees of ruggedness and environmental resistance. It is suggested that the Army consider utilizing an existing device rather than specify requirements that may necessitate a new or modified design.

These devices can be used to read out AIRS by simply providing an adapter plug, wiring harness and switch box for mating with the AIRS test connector.

PGU Description

The PGU shall form part of the ground equipment for the AIRS and shall be a compact ruggedized portable piece of equipment. The PGU shall plug into a test connector on the AIRS unit. A diagram of the unit is shown in Figure 57.

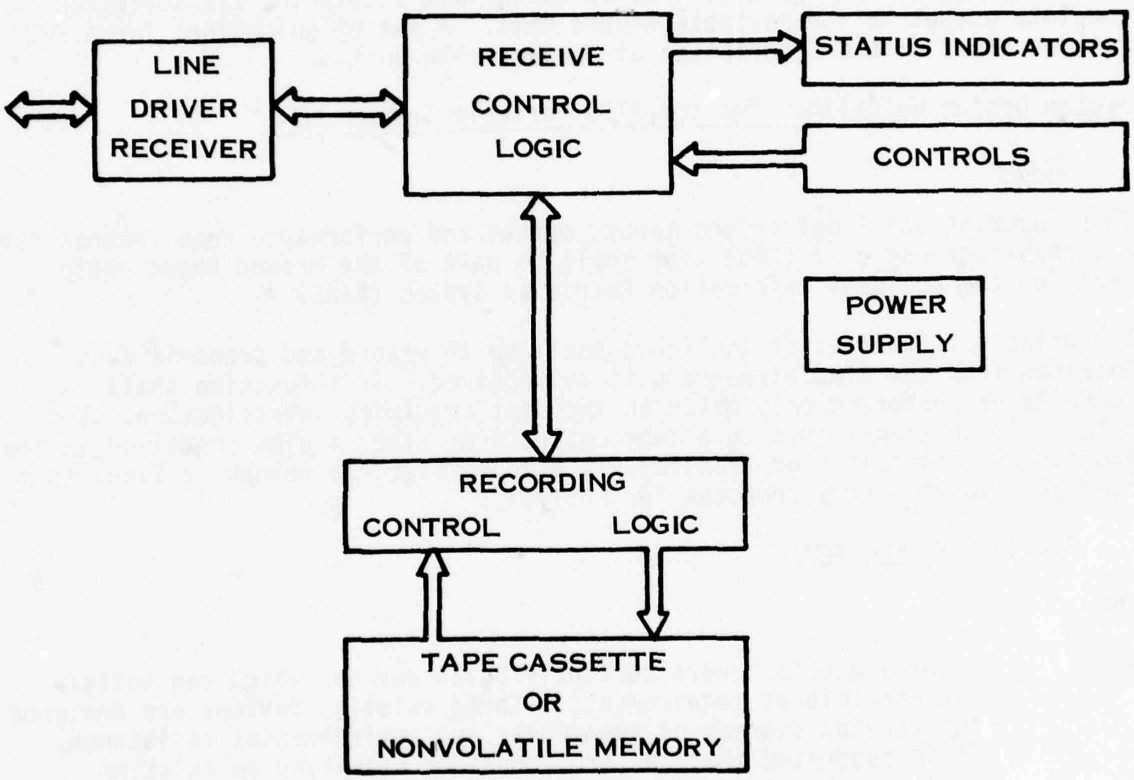


FIGURE 57. PORTABLE GROUND UNIT, BLOCK DIAGRAM

The PGU shall contain controls to enable the operation of the unit together with indicators to indicate its mode and status. It shall contain a tape cassette unit or equivalent nonvolatile memory system to enable the AIRS EAROM data to be recorded. The PGU shall provide two interfaces both RS232 compatible; one shall interface with the AIRS and one shall interface with a modem for interfacing with voice grade telephone communications.

General Requirements

General requirements for the PGU have not been determined relative to size, weight, cost, and environment since it was suggested that existing hardware be considered.

Size

The PGU shall not exceed the following envelope: TBD

Weight

The PGU shall not exceed TBD lbs.

Power

TBD

Temperature

TBD

Transit Case

The PGU shall be housed in a transit case.

Functional Characteristics

The PGU is shown in the system block diagram (Figure 57). When connected to an AIRS, information shall be transmitted from it to the PGU via a serial digital link which is RS232 compatible. The AIRS unit shall routinely inspect one of its discrete inputs to determine if the PGU is connected. If the discrete is sensed, it shall enable the RS232 output port to the PGU and shall transmit the contents of the EAROM to the PGU in 8 bit bytes. When the PGU is connected to a modem via the RS232 output interface, the data contained in the PGU shall be transmitted out in serial fashion.

Electrical Requirements

AIRS - PGU

This interface shall be compatible with RS232 standards in terms of data transmission. Data format shall be one start bit, eight data bits and one stop bit. The baud rate shall be 9600 baud.

A single discrete shall be provided to indicate to the AIRS unit that the PGU is connected. This signal shall be connected to circuit ground.

PGU Front Panel Controls and Indicators

Toggle Switches

The following functions shall be provided:

Write Mode	-	This function shall cause the contents of the AIRS EAROM module to be transferred to the PGU.
Read Mode	-	This function shall cause the contents of the PGU memory to be read out.

Indicators

Status indicators shall be provided as follows:

WRITE	-	WRITE is in progress.
READ	-	READ is in progress.
CLEAR TO SEND	-	Indicates when connected to the modem that communication has been established with receiver and line is ready to receive data.

An Existing PGU Description

As an example, included in the following pages is a description of an existing PGU design.

The device is a Model 4000P Universal recorder manufactured by Datum Incorporated, Anaheim, California. Some of these units are currently being used by the U.S. Army for other purposes. The device is housed in a ruggedized case, but is restricted to an operational temperature range of 0 - 50°C and requires 115 VAC 60 Hz power. This device can be redesigned for a broader operating temperature range and for operation on 115 VAC, 400 Hz if desired by the Army.

Model 4000 General Description (Figure 58)

The system components identified in the block diagram are mounted in the system chassis. The front panel holds the tape transport and all controls and indicators. The power supply is mounted to the chassis and rear panel directly behind the transport. The interface and control electronics are located adjacent to the power supply and tape transport. All I/O connections are located on the rear panel. A removable cover encloses the entire system and, when removed, allows uncomplicated access to all system components for servicing.

STANDARD MODES OF OPERATION

Mode	Manual Initiate	and/or	Override
Write Tape	Yes		Yes
Read Tape	Yes		Yes
Rewind Tape	Yes		No
Command Inhibit	Yes		Yes
Write File Gap	No		No

OPTIONAL MODES OF OPERATION

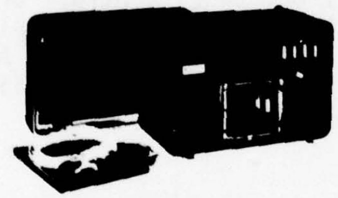
Option No.	Mode	Manual Initiate	and/or	Override
1	Parallel Output	Yes		Yes
	Parallel Input	Yes		Yes
2	Transport Select[1]	Yes		Yes
3	Transmit Status	No		No
4	Tape Search by Record Count[2]	No		No
	Tape Search by File[2]	No		No
	Rewrite previous Record	No		No
	Edit Mode	No		No
	Reverse Motion	No		No
	Read One Record	No		No
5	Block Length Increase[4]	No		No

[1]Automatically included in dual transport version.

[2]Uses three search length characters.

[3]Actually increases the search control characters to two — one for forward and one for reverse.

[4]Block length may be increased in increments of 1024 bits to a total of 4,096 bits or 512 characters.



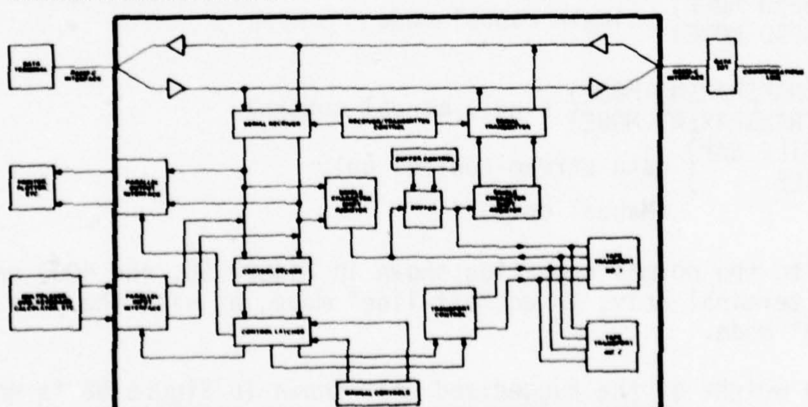
Model 4000-P Portable Ruggedized Unit for field use or in dust and humid environments

SPECIFICATIONS — MODEL 4000 UNIVERSAL RECORDER

Character lengths	Jumper selectable 5, 6, 7 or 8-bit character lengths.
Baud Range	0 through 9990, in 10 baud increments at absolute frequency stability ± .01%.
Manual Capability	Manual override of most controls offered (in addition to manual initialization and remote override).
Buffered Operation	*Standard feature. Provides greater* packing efficiency on tape. In the write mode, buffered data is sent to the selected transport when the buffer is full or on receipt of "end of record character" or "with write mode off" control characters.
Standard Buffer Length	1024 bits. Longer lengths may be specified on applications where packing efficiency is critical.
Dimensions:	
Desk Top Unit	8" high x 12" wide x 16" deep
Rack Mounted Unit (for standard 19" rack)	*8¾" high x 19" wide x 18" deep*
Weight	Less than 40 lbs.
Operating Temperature	0° to 50°C.
Relative Humidity	15% to 85%, *no condensation*
Storage	25° to 125 C, no condensation
Power	100 Watts, 115V, 60 Hz

MODEL 4200 TAPE TRANSPORT OPERATING CHARACTERISTICS

Operating Speed	30 IPS read/write, 120 IPS rewind
Bit Density	800 BPI, NRZ
Storage Capacity	Maximum capacity at 800 BPI, 300,000 characters of storage (300 ft. cassette) (512 buffers).
Track Format	2 track, dual gap, read after write, with error detection



THE DATUM MODEL 4000 UNIVERSAL CASSETTE RECORDER BLOCK DIAGRAM

FIGURE 58. THE DATUM MODEL 4000 UNIVERSAL CASSETTE RECORDER

The Datum Model 4000 Cassette System is designed to continuously write and read data to and from a cassette cartridge. The 4000 contains interface circuits compatible with RS232C devices (terminal or data set). Eight-bit parallel I/O devices, including special parallel interfaces to devices such as the Hewlett-Packard 9800 Series Calculators, are also available. A 20 ma, full-duplex current-loop teletype I/O is also available. The RS232 ports can accommodate continuous data rates up to 9600 baud. The parallel I/O can operate up to 1500 characters per second (8 bits per character) can be continuously input to the 4000, since the unit contains "ping-pong" buffers that alternately accept data from any of the I/O ports and transfer the data to the cassette transport.

The Model 4000 can be controlled from the front panel or from DATA STREAM CONTROL CHARACTERS. The unit can be commanded to write, read, search for a particular record, edit a record, rewind, and write an end-of-file gap. Data can be written on the tape in record lengths from one to 512 characters. Buffers are available in lengths of either 128 characters or 512 characters. If records of lengths other than 128 or 512 characters are desired, a record can be terminated by sending an ASCII encoded carriage-return character to the unit through any of the I/O ports.

Referring to Figure 58, it may be seen that the Model 4000 normally operates in conjunction with a communications terminal and data set (modem) as a storage device. The recording of data as it passes between the terminal and the data set may be controlled manually with front panel controls or remotely through the use of commands transmitted via the data stream. The playback and transmission of recorded information is similarly controlled. All front panel manual controls except reset have data stream "commands" available as well. The standard set of controls are as follows:

a. ENTER WRITE MODE) single manual control
b. LEAVE WRITE MODE)
c. ENTER READ MODE) single manual mode
d. LEAVE READ MODE)
e. REWIND
f. ENTER TRANSPARENT MODE) single manual control
g. LEAVE TRANSPARENT MODE)
h. WRITE FILE GAP) data stream control only
i. READ FILE)
j. RESET (Manual only)

In addition to the normal operation shown in Figure 58, the 4000 may be used with a data terminal only, in an "off-line" mode, or with the data set only, in a "remote" mode.

The size and weight of the ruggedized unit shown in Figure 58 is not listed thereon. For the ruggedized Model 4000P version, the size is 18 X 12 X 13.5 inches, and the weight is 41.5 pounds.

7.5 RELIABILITY AND MAINTAINABILITY

Reliability and maintainability estimates were made and are summarized in Table 40.

Reliability

A reliability analysis was conducted for the AIRS components and is summarized in Table 41. Based on today's technology and failure rate data, a mean-time-between-failures (MTBF) of 5682 hours is predicted for the total system. However, increasing availability of higher density, lower power components will substantially reduce the present design so that a reasonable, conservative projection of the system in 1980 technology is an MTBF of 7,692 hours for the AIRS. Similarly, the MTBF of the AIRS airborne unit without sensors was calculated to be 6,944 hours using 1977 technology, and is predicted to be 10,204 hours in 1980. The above MTBF's relate to the reliability of the AIRS Electronic Unit and only the added sensors used exclusively for AIRS. As such, these numbers have a meaning related to a maintenance removal rate since they predict a failure rate for added equipment only.

For data acquisition systems utilizing a number of parallel input signal paths such as AIRS, the functional reliability of the system is often defined as that calculated from failures which would cause loss of more than one channel of data. Using this criteria, approximately 40 λ's would drop out of the tabulation shown on Table 41. This would result in a system MTBF approximately 10,000 hours using 1977 technology.

Reliability Calculation Rationale

1977 electronic component failure rates were derived in accordance with Airborne Inhabited Section 3.0 of MIL-HDBK-217B. The average failure rates were used in lieu of Section 2 (detail failure rates) since total stress and temperature information is not available. However, past experience has shown that section 2 calculations are conservative due to the stringent derating policy employed by Hamilton Standard on component stress and temperature.

All constituent components of the AIRS unit are screened. Screening level varies from a standard JAN product to burned-in devices and selected hi-rel screening in the form of JTX and MIL-STD-883 Class B processing. Components are military temperature range. Microcircuits and semiconductors are all hermetically sealed.

The accelerometer and pressure transducer failure rates were taken from Hamilton Standard service experience. Potentiometer failure rates were estimated on related design and elsewhere.

The resultant MTBF was then assumed to be the serial summation of all the component failure rates.

Projected failure rates for 1980 are based on the update of published failure rate data for standard parts and on the design complexity reduction based on normal evolution of higher component densities which result in less interconnects, less discrete components, and more efficient heat sinking.

TABLE 40. RELIABILITY AND MAINTAINABILITY SUMMARY - AIRS

(Includes AIRS unit, accelerometer assembly, fine altitude transducer and two flight control position pickoff's in the UTTAS application.)

*	Reliability (MTBF)	7,692 Hrs
*	Mean Time Between Unscheduled Removals (MTBUR)	7,700 Hrs
*	Maintenance Man-Hours/ 1000 Flt. Hrs Organizational Level (Scheduled & Unscheduled)	0.13 Removals/1000 Hrs
*	Maintenance Man-Hours/ 1000 Flt. Hrs (Intermediate Level (Scheduled & Unscheduled)	0.76 Hrs/1000 Flt. Hrs
*	Depot Level	Suggest return of subassemblies to manufacturers

TABLE 41. AIRS PRELIMINARY RELIABILITY PREDICTION

	1977		Projected 1980	
AIRS UNITS:	λ	MTBF	λ	MTBF
Disc/Freq Buffer	4.593		4.0	
Analog Buffer A/D	14.76		13.0	
Processor, NVM & Logic Control	21.54		16.0	
Power Supply	49.08		20.0	
NVM Interface, WD Timer	34.15		30.0	
PC boards, Interconnection	20.00		15.0	
	144.1	6,944	98.0	10,204
AIRS SENSORS:				
Accelerometers (4)	12.0		12.0	
Pressure Transducers	10.0		10.0	
Potentiometer (2)	10.0		10.0	
	32.0	32,500	32.0	32,500
TOTAL SYSTEM:		5,682		7,692

Maintainability

One of the significant advantages of the proposed AIRS system is its high level of BIT. A desirable maintainability objective for the AIRS system is to install the system on the aircraft and then operate with no need for periodic maintenance. This objective can be approached by having a system that seldom fails and annunciates, with a high degree of confidence, when a failure has occurred and has unlimited life. The proposed AIRS approaches these objectives. The unit MTBF is estimated to exceed 10,000 hours. The BIT is estimated to detect 95% of all hardware faults in the electronics unit.

In addition, the BIT effectiveness increases further in detecting faults which affect more than one signal input channel.

The reliability analysis estimates that the added AIRS sensors collectively exhibit a reliability in excess of 30,000 hours. Hence, AIRS sensor faults are expected to be very infrequent. The AIRS electronics unit can monitor input sensors for a noncredible range and to a certain extent range rate. Therefore, some types of sensor failures can be detected by the on-board BIT.

Since the system has no aircraft or mission operational purpose, malfunction of the AIRS hardware will only be picked up by its own BIT, or, for the small percentage of failures undetected by BIT, would be picked only when data is read out and analyzed by the ground portions of the AIRS.

The aircraft incident rate is expected to be such that the odds of reading data out for investigative purposes in any given year on a particular vehicle will be very low.

Periodic Ground Software Based AIRS Checks

As an adjunct to the AIRS BIT, consideration should be given to extracting data from each Aircraft's AIRS on a calendar basis or on accumulated flight hours. A reasonable maintenance interval would be every 1,000 flight hours.

The data would be routinely sent to the central computer facility, and a software analysis of the information would be conducted. Section 7.7 (Ground Data Processing) identifies the type of data checks and correlation analysis that can be run to validate the incoming data. A diagnostic advisory message is automatically generated by the program. This could be sent back to the organizational level for appropriate action.

AIRS Maintenance Readout Unit

When an AIRS sensor malfunction is detected or when a malfunction is suspected in a system or sensor which "feeds" AIRS, it may be desirable to be able to examine the sensor output on the aircraft. If a sensor replacement is made it would also be beneficial to read the sensor output for an aircraft check and/or calibration purposes. To facilitate this, an AIRS maintenance readout unit is suggested.

The following guidelines are provided for the design of such a unit.

Scope

This document defines the input, output and performance requirements for an AIRS Maintenance Readout (MRU) that could form part of the maintenance support equipment for the Accident Information Retrieval System (AIRS).

The principal function of the MRU shall be to enable aircraft signals connected to the AIRS to be selected for display on the unit. The MRU can also be utilized during initial aircraft installation for system checkout in addition to its primary maintenance support role.

Applicable Documents

Military

MIL-T-21200L	Test Equipment for Use with Electronic Equipment Spec., for
MIL-STD-454E	Electronic Equipment Standard General Requirements for
MIL-STD-461A	Electromagnetic Interference Characteristics Measurement of
MIL-STD-462	Electromagnetic Interference Characteristics Measurement of
MIS-T-5422F	Testing, Environmental, Airborne Electronic and Associated Equipment

Other

AIRS System Specification

Unit Description

The MRU shall form part of the support equipment for the AIRS and shall be a compact ruggedized portable piece of equipment. The MRU shall plug into a test connector on the AIRS unit. A total AIRS system checkout/calibration shall encompass checks of the AIRS unit itself together with the relevant aircraft sensors and wiring. Aircraft power shall be available for these tests and shall also power the MRU. The unit is shown in Figure 59. Two modes of operation shall be available, Display Input Data and Display Memory Data. When the Display Input Data Mode is selected, the AIRS unit shall receive commands from the MRU requesting a parameter for display, together with the type of display required; i.e., decimal octal or engineering units. The AIRS unit shall interpret these commands and send back the data for display. When the display is selected to Display Memory Data Mode, selected words shall be read from the AIRS EAROM memory.

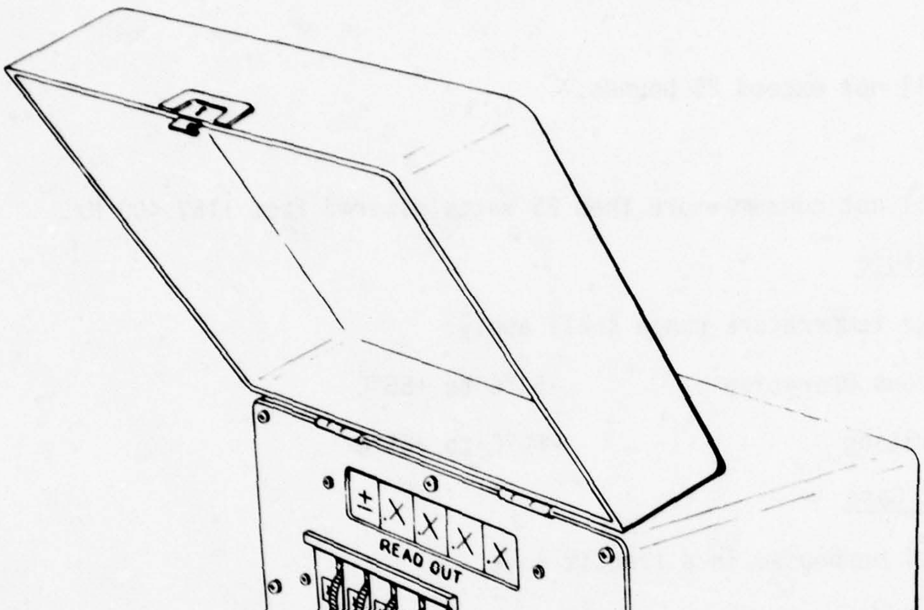


FIGURE 59. MAINTENANCE READOUT UNIT

General Requirements

Size

The MRU shall not exceed 12 X 12 X 10 inches.

Weight

The MRU shall not exceed 25 pounds.

Power

The MRU shall not consume more than 25 Watts powered from 115V 400 Hz.

Temperature

The following temperature range shall apply:

Continuous Operation	-54°C to +55°C
Nonoperating	-60°C to +85°C

Transit Case

The MRU shall be housed in a transit case.

Functional Characteristics

The MRU is shown in the system block diagram of Figure 60. Information shall be exchanged between the AIRS unit and MRU via a bidirectional digital buss. The AIRS unit shall routinely inspect one of its discrete inputs to determine if the MRU is connected. When it is, it shall acknowledge the MRU and wait for information to be transmitted to it from the MRU.

To obtain a display of a selected parameter, the parameter number shall be set in on the MRU thumbwheels. (See Figure 59) The right-hand thumbwheel is used to set Decimal (DCL) Octal (OCT) or Engineering Units (EU). The ENTER' key shall then be pressed. The AIRS units shall interrogate the thumbwheels and MRU memory. It shall acquire the requested parameters and transmit it to the MRU in a compatible format for display. The system shall remain in this mode, with the display being continually updated until a further entry is made or the 'RESET' key is pressed. The MRU memory shall incorporate all scaling information for conversion of the parameters to engineering units, as well as containing subroutines and display driver routines.

Selecting the Memory Data Mode (MDM) shall enable the MRU to display selected memory location of the AIRS EAROM. The memory address shall be entered via the thumbwheels, the sequence shall be similar to that described above, and the display shall operate only in the decimal counts mode when displaying memory data.

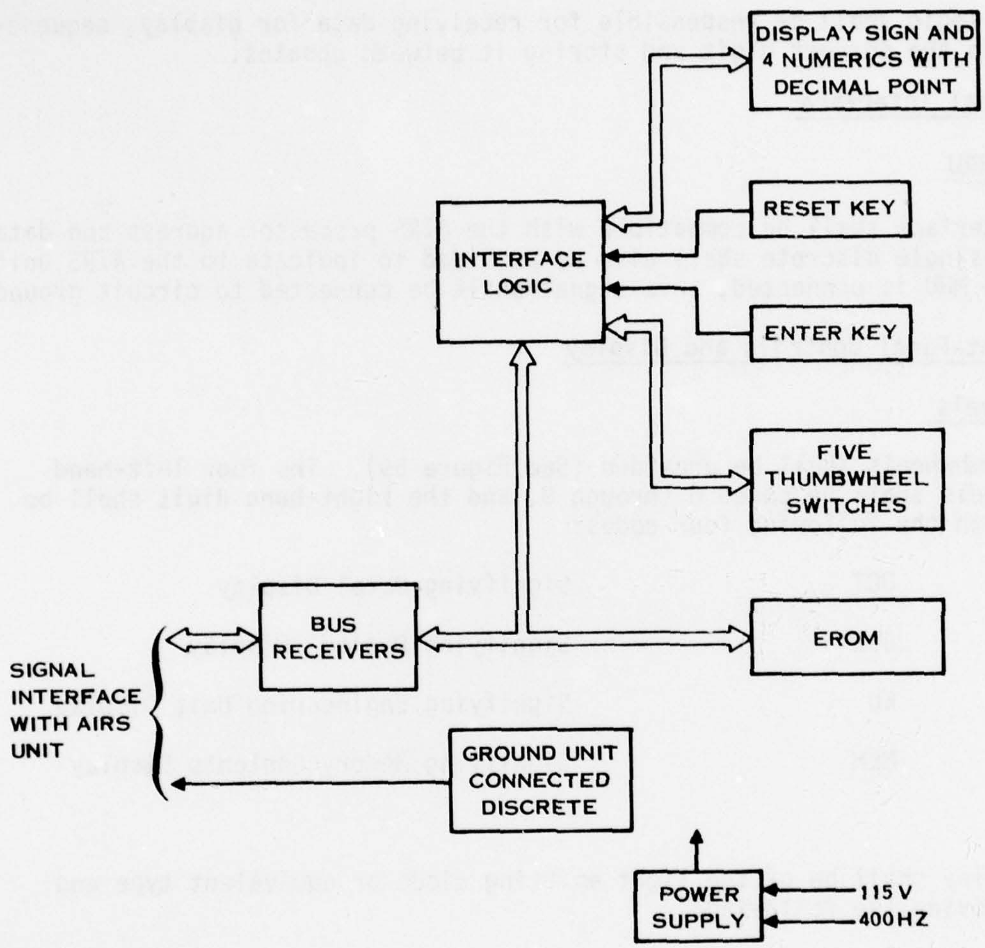


FIGURE 60. MAINTENANCE READOUT UNIT BLOCK DIAGRAM

An EAROM memory of 1K X 8 bits shall be provided for storing information pertinent to displaying data in engineering units, conversion and display subroutines.

Receive logic shall be responsible for receiving data for display, sequencing it to the correct digit and storing it between updates.

Electrical Interface

AIRS - MRU

This interface shall be compatible with the AIRS processor address and data bus. A single discrete shall also be provided to indicate to the AIRS unit that the MRU is connected, this signal shall be connected to circuit ground.

MRU Front-Panel Controls and Display

Thumbwheels

Five thumbwheels shall be provided (See Figure 59). The four left-hand thumbwheels shall be coded 0 through 9, and the right-hand digit shall be coded with the following four codes:

OCT	Signifying Octal Display
DCL	Signifying Decimal Display
EU	Signifying Engineering Unit Display
MEM	Signifying Memory Contents Display

Display

The display shall be of the light emitting diode or equivalent type and shall provide the following:

One sign display of + or -

Four numeric display 0 through 9 with integral decimal point.

Pushbuttons

Two pushbuttons shall be provided as follows:

ENTER	Shall be used to enter thumbwheel data and transmit to AIRS unit.
RESET	Shall be used to terminate or cancel a mode.

Maintainability Estimate - AIRS

Since the BIT level of the system is estimated to be 95% or greater, and the only other means for detecting faults is the suggested 1,000 flight hours software analysis, the MTBF (Mean Time Between Failures) of the system components is nearly equal to the MTBUR (Mean Time Between Unscheduled Removals). For the projected 1980 system MTBUR = 7,700 Hours. In a 1,000 operating hour interval the mean removal rate would be

$$\frac{1,000}{7,700} \text{ removals} \qquad \text{(0.13 removal per aircraft per 1,000 hours)}$$

The MTTR (Mean Time To Repair) at the organizational level for the AIRS is estimated to be 1.0 hour. This would include removal and replacement of any AIRS component on the aircraft along with hookup and readout of data using the maintenance readout unit before and after replacement.

At the organizational level, this means that the MMH/1,000 F.H. due to unscheduled rework would equal 0.13 hour/1,000 flight hours. Added to this would be 0.25 hour at 1,000-hour intervals to extract data for maintenance related ground analysis. (For a total scheduled plus unscheduled time of 0.13 + 0.25 = 0.38 hour per 1,000 flight hours.)

At the intermediate level, the mean time to repair AIRS components would be approximately equal to the MTTR for the AIR electronics unit since it is the dominant component from a removal rate and repair time point of view.

Since the package is modular but rigidly fastened together for survivability, removal and replacement of a module (Assumed Lowest Level Of Repair) would take repair time significantly longer than the usual electronics package disassembly and reassembly.

Two hours is assumed for the total task including test, disassembly and module removal, replace reassembly and retest. Testing is assumed with an automated shop test rig which can fault isolate to the module level.

The mean time to repair times the removal rate per 1,000 hours is

$$2 \times 0.13 = 0.26 \text{ Hr/1,000 Hrs.}$$

The man-hours to process AIRS data for each aircraft every 1,000 hours is added to the above. 0.5 hour per data set is estimated.

Total intermediate level MMH/1,000 FH (scheduled or unscheduled) can be considered the sum of the repair time plus data processing setup time

$$0.26 + 0.5 = 0.76 \quad \text{MMH/1,000 FH}$$

For repair of individual sensors and electronics unit subassemblies, it is recommended that the units be returned to the manufacturer. With a fleet of 1,000 aircraft operating for one year, an estimated 50 items will be in need of repair at the subassembly level. This number indicates that returning subassemblies to the manufacturer may be the most economical approach.

7.6 AIRFRAME INSTALLATION CONSIDERATIONS

The effort in this area consisted of determining the location of system components in a helicopter airframe based on the survivability of AIRS itself and considerations of best locations to make effective measurements and at the same time keep installation size, weight, and cost down. The installation requirements were reviewed with an airframe manufacturer, and preliminary estimates were made of man-hours to install an AIRS on a helicopter either as a kit or during aircraft manufacture.

Detail discussions on installation factors are provided in the following sections.

Survivability Considerations and Airframe Location

The general placement of the AIRS electronics unit can be determined by the process of elimination as follows, using the UH-60A as a guide (see Figure 61):

Its placement in the tail cone or tail rotor pylon is not recommended since the most likely break in the fuselage is at the forward end of the tail cone. A break there would separate the unit from its power source, which is undesirable.

Its placement in the fuselage between the main rotor station and the forward end of the tail cone is not recommended because of its proximity to the fuel tanks, the fuel lines, and above the fuselage, the engines, and the auxiliary power unit. Even though the post-crash fire potential has been greatly minimized through the use of crash-resistant fuel systems, it has not been eliminated. For example, if the helicopter rolls on its side, the exhaust of the lower engine impinges directly on any material on the ground and could lead to fire even though no fuel may have been spilled.

Its placement in the nose of the helicopter forward of the crew or under the cockpit and cabin floors is not recommended. These locations are more susceptible to crash damage than most others. Both nose-on impacts into rigid abutments and penetration of the fuselage underside by rocks and tree stumps may be anticipated in the stress and rough environment of a conflict. The crushing of the nose is not expected to encroach on the crew's living space unless the nose-on impact occurs at high speed. Even so, there is little space available in the cockpit area that could be used to locate the AIRS unit.

Its installation above the fuselage shell in the forward section of the main rotor pylon is not recommended. In accidents in which the helicopter pitches or rolls over or impacts inverted, this area would likely be susceptible to damage and displacement.

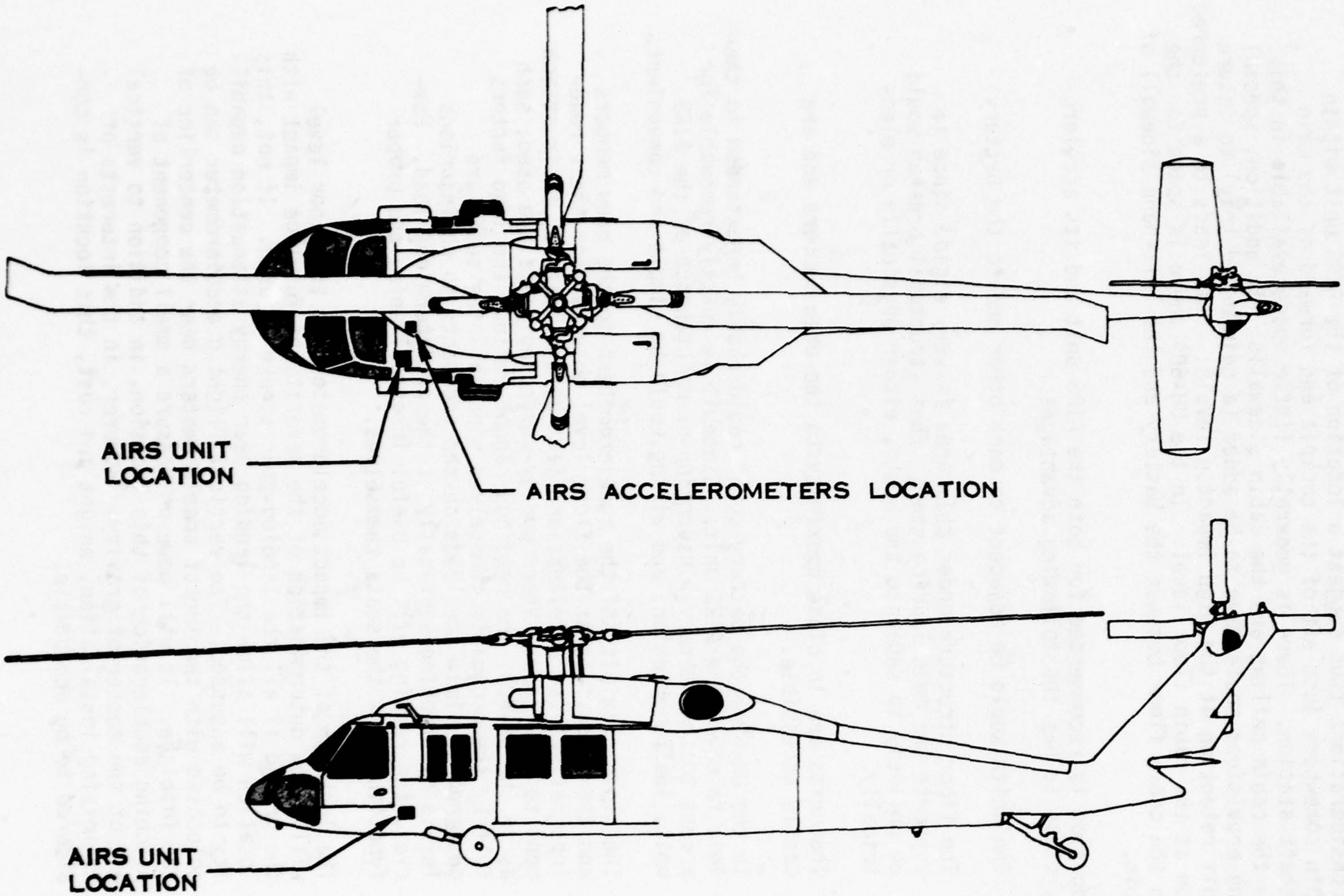


FIGURE 61. TYPICAL AIRS COMPONENTS LOCATION

These considerations thus suggest a location of the AIRS unit within the cabin somewhere just aft of the cockpit and forward of the main rotor shaft station. There is generally little space available in this area in the cabin ceiling and the cabin sidewalls. In addition, special mounting provisions would have to be added (a reinforced tray) to insure AIRS unit retention at the high impact g levels. This leads to a preferred location at the cabin floor level. In the UH-60A there is space for the unit on the cabin floor between the battery and the left-hand sidewall of the cabin.

This location is recommended for both the AIRS unit and its accelerometers, since it has the following advantages.

* The units would be adjacent to each other and to the battery.

* The floor structure under this area is very rigid, since it supports the main landing gear. Thus structural breakup would be unlikely to separate the units, either physically or electrically.

* The units are in close proximity to the crew members and are easily accessible.

* In the UH-60A, the battery cover could easily be extended to the left to cover the AIRS unit. Since it is quickly removable for access to the battery, inspection or maintenance of the AIRS unit, instrumentation, and wiring would be simple and convenient.

* The close proximity of the accelerometers to the crew members and their location at the floor level ensures that their readings reflect the accelerations felt by the seats at their attachment to the floor. Where energy-absorbing seats are used, such as in the UH-60A, the readings cannot reflect the load factors felt by the occupants themselves since all the seats are designed to limit the loads on the occupants to noninjurious levels by stroking vertically at the predetermined load. However, the reading will be useful in establishing the proper functioning of the seats themselves.

* The location of the impact accelerometers at the floor level will allow determination of the severity of fuselage impact with the ground if all the landing gear stroke is used. If not, this location will allow the landing gear energy attenuation capability to be assessed. The vertical flight g accelerometer can be colocated with the impact accelerometers near the centerline of the fuselage. It will however measure a small component of pitching acceleration of this location, in addition to vertical g's at the center of gravity. However, in the interests of minimizing installation, weight and cost, this location is considered to be acceptable.

One disadvantage of this AIRS equipment location is the possibility of damage to the unit that may be caused by heavy objects or cargo which may be displaced in a crash. The Army's awareness of the need to restrain such cargo should minimize such occurrences.

Other elements of the AIRS do not require special survivability considerations since they measure signals indicative of the in-flight operation. These would include altitude and airspeed transducers and potentiometer/linkage assemblies for measurement of pilot control inputs.

Aircraft and Interface Installation Details

A set of preliminary installation guidelines for aircraft manufacturers was prepared for new aircraft application such as UTTAS and AAH. The guidelines are:

AIRS Installation Guidelines

1. 28 VDC Line (Battery to AIRS unit) installed to withstand 150-g 10-millisecond impacts as a design goal. Leads to be as short as possible with extra bends to allow for differential supporting structure movement.

   3-axis accelerometer excitation and signal leads to AIR unit installed to withstand 150-g 10-millisecond impacts as a design goal. Leads to be as short as possible with extra bends to allow for differential supporting structure movement.

2. AIRS unit installed to take 150-g 10-millisecond impacts as a design goal. (See Figure 62.) Mounting would be via a hardmount capable of taking the impact force.

3. New sensors to be installed.

   * Altitude transducer in static line

   * 3-axis accelerometer (impact measure)

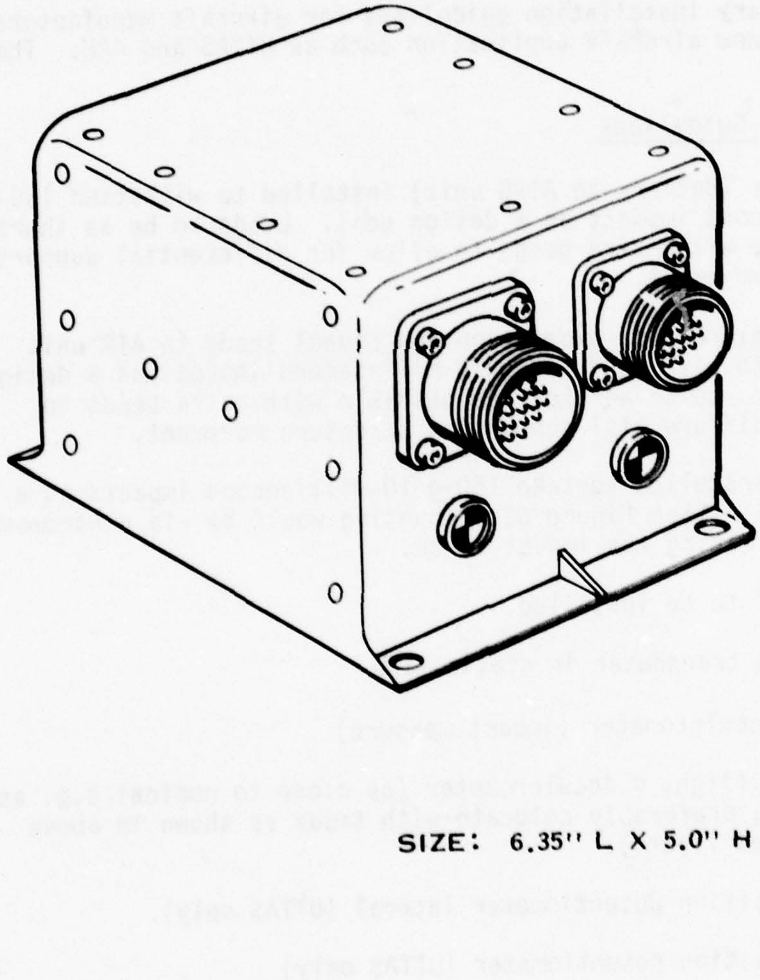
   * Vertical flight g accelerometer (as close to nominal c.g. as possible, preferably colocate with triax as shown in above referenced figure).

   * Stick position potentiometer lateral (UTTAS only).

   * Pedal position potentiometer (UTTAS only)

4. Determine best compromised location of AIRS unit for:

   * Unit survivability



SIZE: 6.35" L X 5.0" H X 6.0 W

FIGURE 62. MECHANICAL CONCEPT AIRS UNIT

* Short wiring run from essential buss battery and wire survivability. AIRS unit circuit breaker would be adjacent to battery not at normal circuit breaker panel.

5. Determine best location for impact triaxial accelerometer unit.

   * For measuring impact forces and easiest extrapolation to other locations.

   * Minimum AIRS unit to impact triax wiring run and to optimize wiring survivability.

6. Determine best location for the vertical flight g sensor. (Colocated with the impact triax is preferred.)

7. Determine the tie points to existing signals in the airframe wiring for the various input parameters to minimize wire runs in terms of installation cost and weight.

8. Determine pneumatic tie-in to static line for the fine altitude transducer.

9. The preliminary AIRS wiring is as shown in Figure 63. Wire sizes, standard practice for airframe manufacturer for low signal levels. Input impedance of all AIRS channels greater than 100,000 ohms.

AIRS would be interlocked with the essential buss switch or any switch that is normally turned on when the aircraft is powered up. The AIRS unit will drop itself off the battery after a suitable time delay when main rotor speed drops below a predetermined value. (See Figure 64).

Power drain 1 amp from 28 VDC when AIRS is activated. All analog signals are input double ended differential for maximum common mode rejection. Low side or one side of a sensor brought in with signal lead. Wires should be twisted. AIRS does not require shielded wires. However, if airframe manufacturer's practice is to shield all wires to protect for radiated EMI, then shield as required. All discretes do not require a separate ground return.

Typical AIRS Installation

In response to the preliminary guidelines, as given above, a typical AIRS installation is quantified. The aircraft installation can consist of the AIRS electronics unit, the control position pick-off assemblies, a vernier altitude sensor, an airspeed sensor, and an accelerometer assembly. In the UH-60A, the AIRS equipment would consist of:

* Electronics Unit

* Accelerometer Assembly (3-axis impact, 1-axis flight)

* Vernier Altitude Sensor

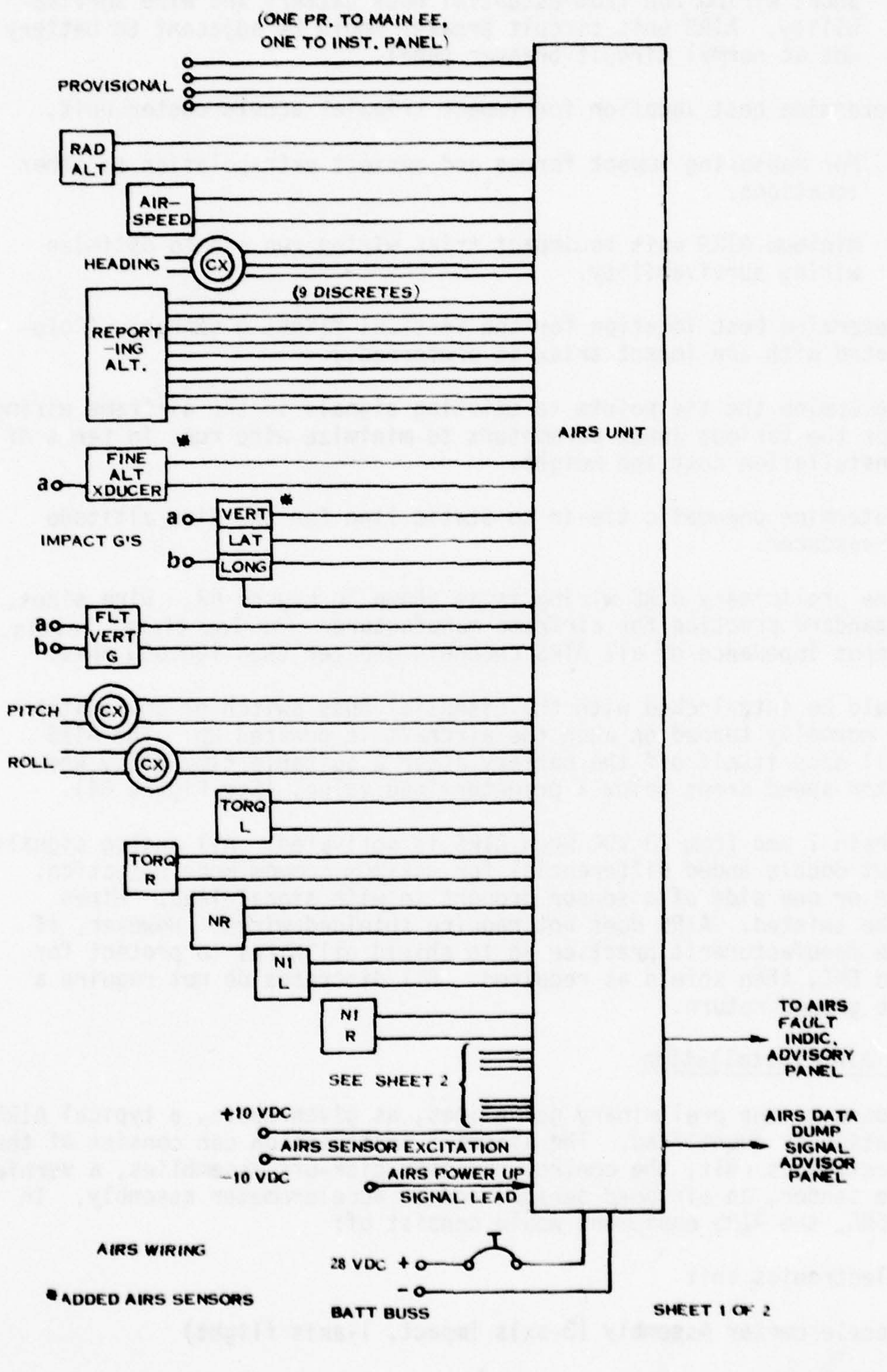


FIGURE 63. AIRS WIRING

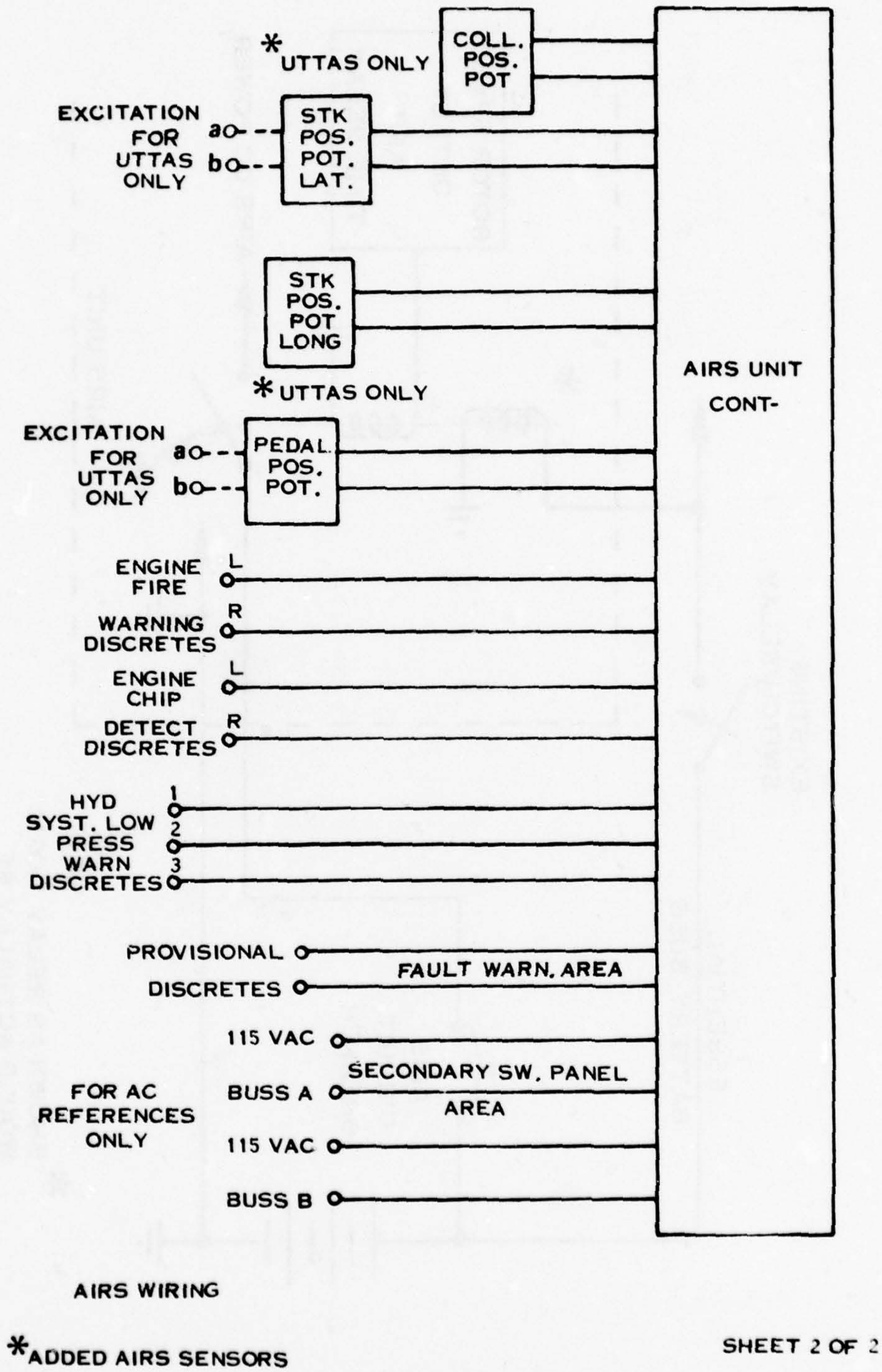
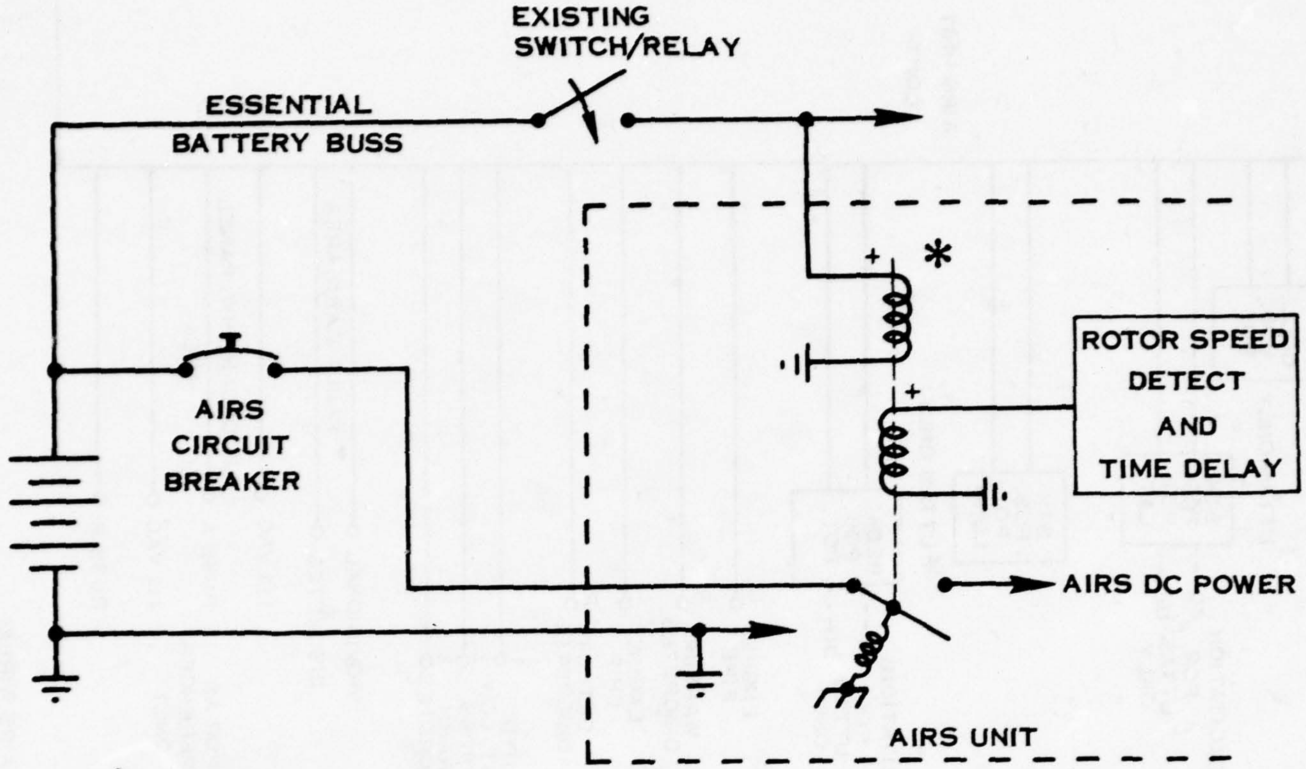


FIGURE 63. AIRS WIRING (CONTINUED)



* SHOWN AS RELAY LOGIC WOULD ACTUALLY BE SOLID-STATE LOGIC AND SWITCHING

FIGURE 64. AIRS POWER UP/DOWN SCHEME

* Yaw Pedal Position Pick-off Assembly

* Lateral Cyclic Position Pick-off Assembly

* Airframe wiring, clamps, conduits, connectors and circuit breaker.

All other parameters are available as electrical signals and do not require special sensors.

Figure 61 shows the location in the airframe of the electronic unit and accelerometers. A more detailed typical layout of these units is shown in Figure 65 relative to the battery. Close proximity to the battery and the short wiring run to the accelerometer assembly will maximize system functional survivability during impact. For other aircraft, a similar arrangement is recommended if possible. At least to the extent that cable runs are kept short between the necessary impact recording elements.

The vernier altitude transducer would be located adjacent to existing pitot-static sensors usually located on a shelf behind the instrument panel in the cockpit and plumbed into an existing static line. A typical installation is not shown since it would be quite simple.

The control position pick-off assemblies would be similar to assemblies currently used to measure control positions as a part of other aircraft systems such as flight controls.

A typical rotary motion pick-off installation is shown in Figure 66.

In the UH-60A, an axial bellcrank sensor location may be implemented similar to that shown for both the yaw pedal position and the lateral cyclic position pick-offs. Other than the potentiometers, the only other nonstock item parts would be two sheet metal assemblies for pot mounting and motion input.

Installation Weight

The weight of the installation over and above the AIRS unit and sensors was estimated for the UH-60A aircraft based on the chosen location of the AIRS units and an estimate of the length of wire running to the accessible signal pick-off points.

Table 42 summarizes the Installation weight data.

AIRS Installation Effort

As a typical example of the effort required to install AIRS, the installation guidelines as described in this section were given to the participating airframe manufacturer, and a preliminary estimate was prepared. The estimate considered installation both as a kit and as part of the aircraft during the original manufacture.

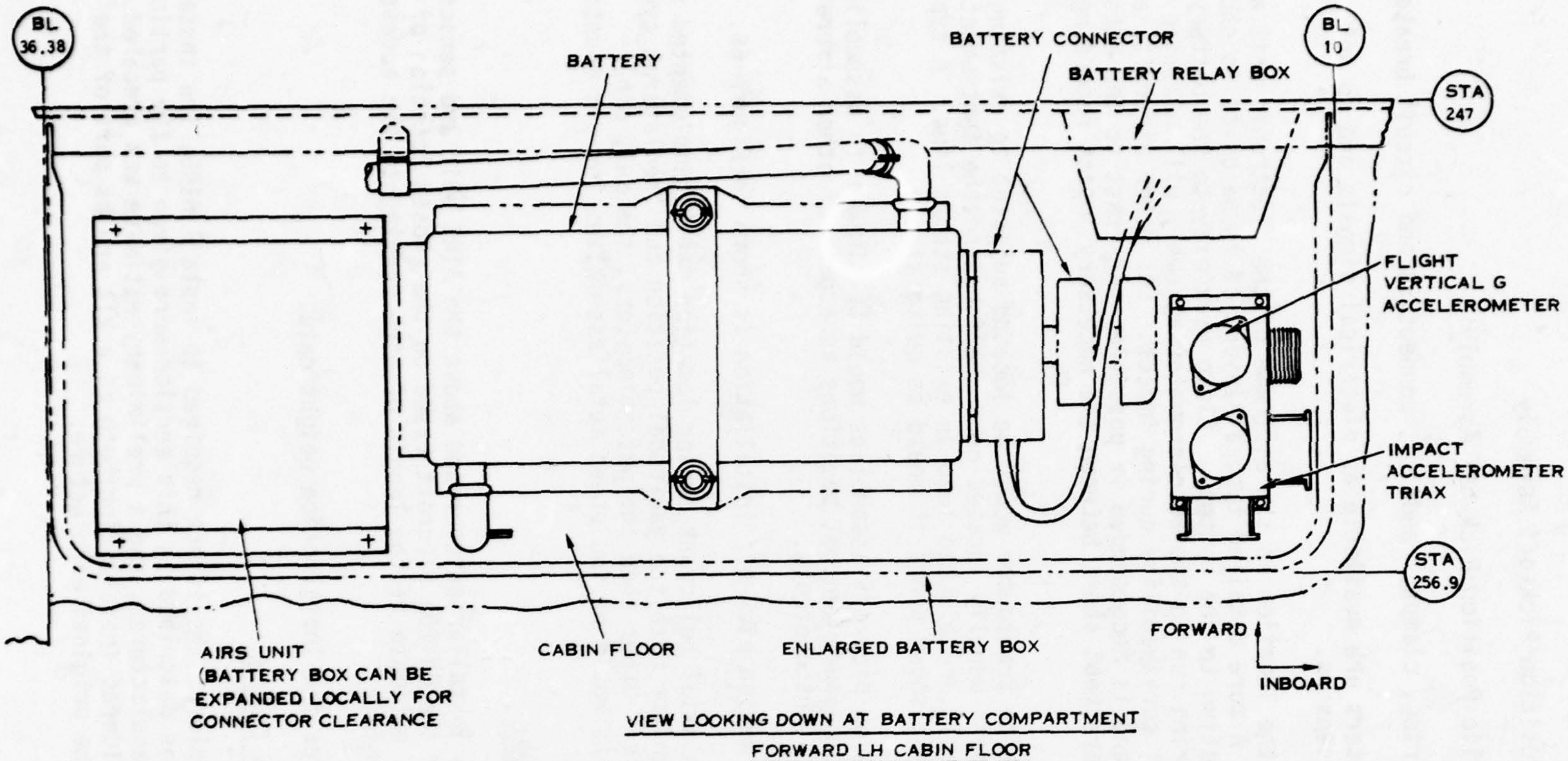


FIGURE 65. TYPICAL AIRS UNIT INSTALLATION

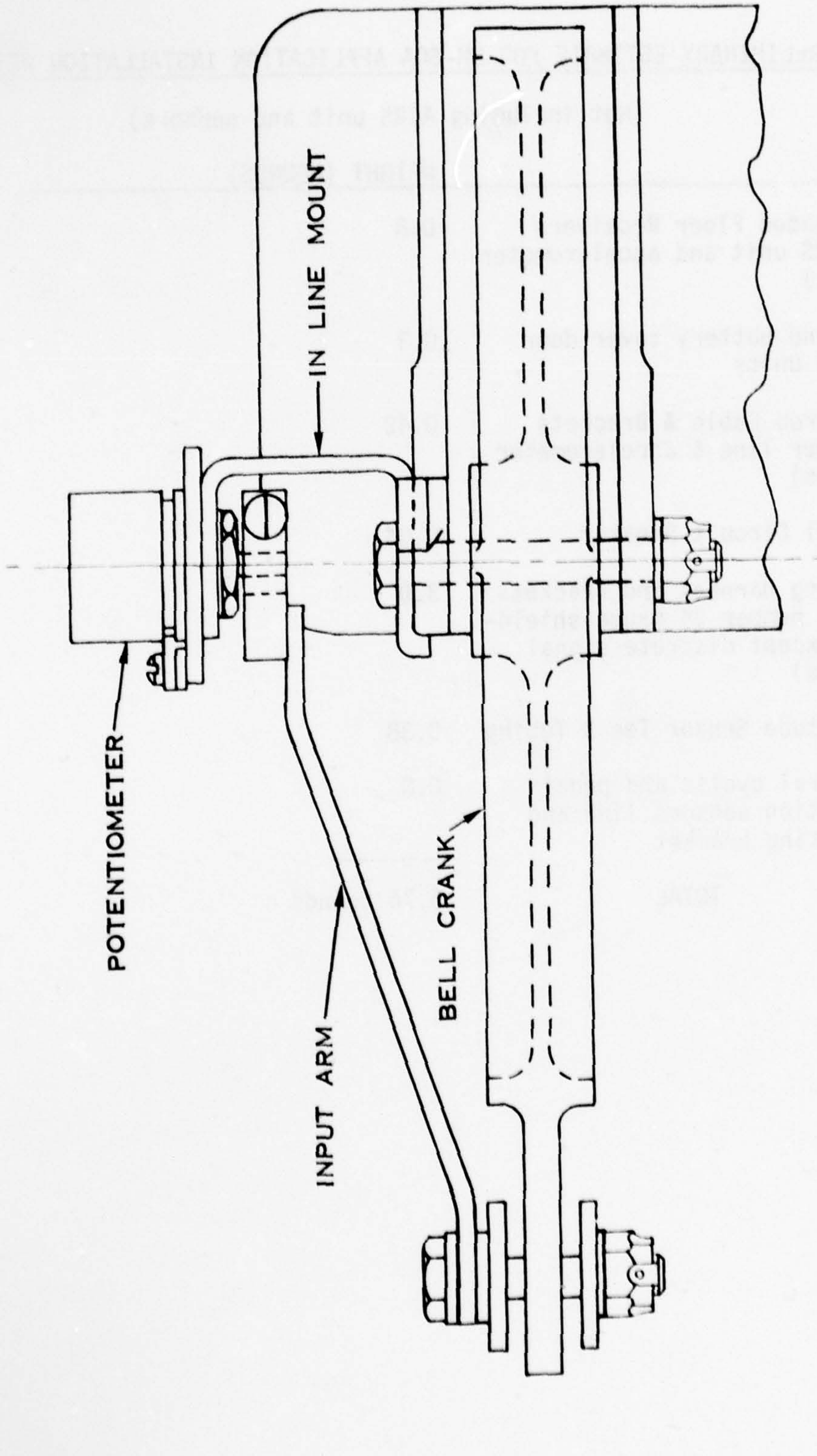


FIGURE 66. RUDDER PEDAL POSITION

TABLE 42. PRELIMINARY ESTIMATE FOR UH-60A APPLICATION INSTALLATION WEIGHT

(Not including AIRS unit and sensors)

	ITEM	WEIGHT (POUNDS)
*	Threaded Floor Receivers (AIRS unit and accelerometer unit)	0.8
*	Extend battery cover door AIRS Units	0.3
*	Armored Cable & Brackets (Power line & accelerometer lines)	0.42
*	Local Circuit Breaker	0.06
*	Wiring Harness and Brackets (All number 24 gauge-shielded except discrete signal leads)	3.0
*	Altitude Sensor Tee & Tubing	0.38
*	Lateral cyclic and pedal position sensors link and mounting bracket	0.8
	TOTAL	5.76 pounds

The man-hour recurring estimates to install the AIRS considered wiring runs, numbers of wires, clamping, armoring, unit and sensor installations, bracketry, threaded floor receivers, connectors, etc.

In addition, the estimate considered standard learning curve factors and estimates for typical lot buys of systems and installation.

Figure 67 summarizes the estimate findings.

It should be noted that proper provisioning of the aircraft in terms of pre-wiring, space, and mounting bolt threaded receivers in place in the floor will reduce the after-aircraft manufacture AIRS installation effort down to a value approximately that of the lower curve shown.

7.7 GROUND DATA PROCESSING

Ground Data Processing can be provided by various methods. Data transfer from remote sites could also be provided by various methods. Data processing alternatives include the following:

(1) A stand-alone minicomputer based facility at a single fixed site. This could be located at USAAAVS and be an extension of an existing minicomputer facility.

(2) Use of a Time Share terminal.

(3) Use of existing Army batch process computer facilities.

In (1) and (3), data could be transferred by physically sending the cassette or transferral via telephone lines using RS232 compatible modems which are readily available. Control of the tape transcription via telephone lines would be by remote computer, and would function in a similar fashion as that described in section 7.3 for generating the PGU tape, except the remote processor would read the tape only.

In (2) above, the "time share" terminal would be transported to near the site. The time share system would consist of AIRS ground software stored in a remote computer under a lease or use charge basis. The portable terminal would consist of a cathode ray tube display and keyboard, telephone modem, and acoustic coupler. Access to time share systems is available from a number of companies such as the CDC KRONOS Tyme Share system on the North American continent. Data transferral would also be via an RS232 compatible modem.

Central Data processing is envisioned to provide such functions as plots of parameters versus time, or groups of appropriatly interrelated parameters versus time. Graphic plots are preferable; however, tabular data could be generated. A business computer compatible magnetic tape could be generated of either the raw data or decompressed data (i.e., gaps removed by filling in with data). These tables could be permanently used for more sophisticated fleet wide data analysis or used as inputs to a flight simulator.

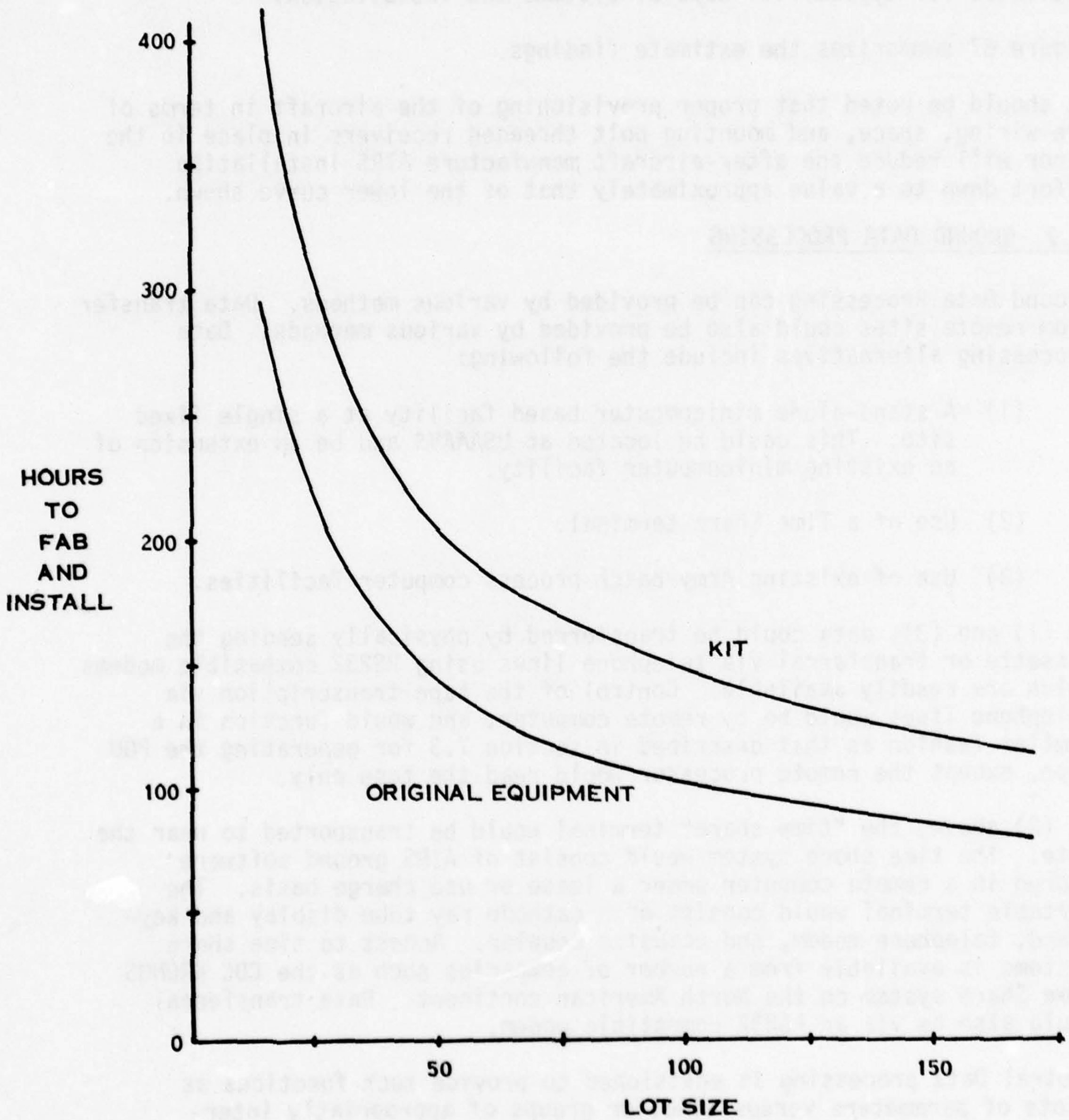


FIGURE 67. TYPICAL AIRS RECURRING EFFORT FOR INSTALLATION

Figure 68 shows the general arrangement of programs that could be developed and installed at an Army central ground computer facility.

Data is received from the AIRS via cassette and/or telephone transmission. The data could be stored in raw form at this point. At this juncture some general-purpose programs could be executed as shown to operate on the data and bring it to the point of correction and conversion. The general purpose software program elements are as follows:

* Data Reconstruction - to real time. (Non-airframe dependent)

* Credibility Analysis - Out of range and range rate. Cross Correlation such as Alt course versus Alt fine versus radar Alt (if present). Correlation of parameters such as vertical g's approximately equal to "one" with aircraft static if data is available. Parameter activity monitor and scatter band analysis. At this point a diagnostic report could be generated to list possible AIRS or AIRS related sensor malfunctions. (The credibility analysis program element would be somewhat airframe dependent, particularly with regard to range and range rate.)

* Data Conversion - to engineering units with any suspect data tagged. (This element is airframe dependent.)

At this point the corrected and converted data could be put on tape and permanently stored: Specific programs could now be called up to support the accident analysis. (The top four elements shown on the right of the referenced Figure are not considered airframe dependent.)

The specific program elements could include the following:

Parameter print versus time. This program would print out all the recorded parameter against time. See Table 43 for example. Parameters would be listed in engineering units in the time sequence that they occurred.

TABLE 43. PARAMETER PRINTOUT VERSUS TIME

RELATIVE TIME FRAME (SEQ. #)	AIRSPEED (KN)	HDG (DEG)	ALT (FT)	PITCH (DEG)	ROLL (DEG)	ETC
7.81	110	99	7000	- 1.0	+5.0	
7.82	112	104	7005	- 1.0	+5.0	
7.83	114	108	7007	- .5	0.0	

ETC.

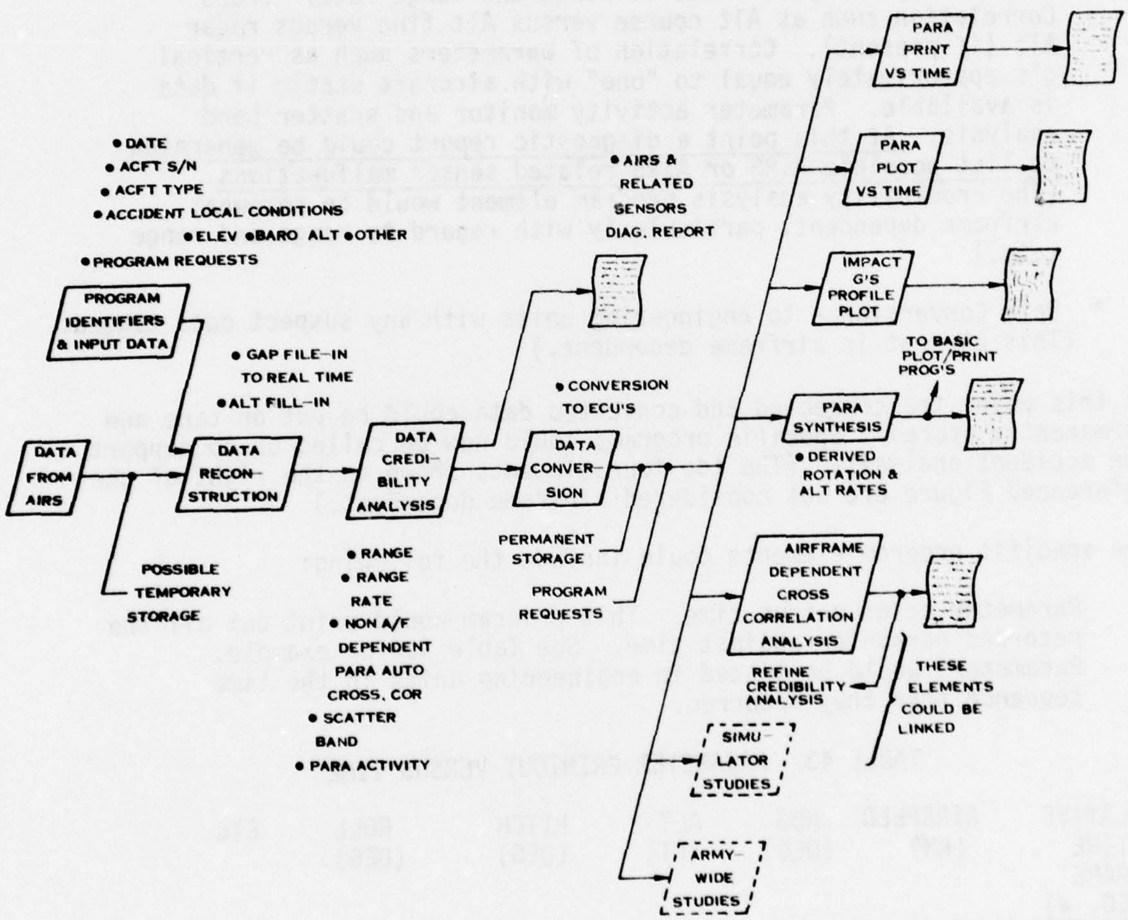


FIGURE 68. AIRS GROUND SOFTWARE OUTLINE

Parameter plot versus time. This data presentation is shown in Figure 69 as a single parameter plot. Figure 70 shows a multiple parameter plot as currently developed for fixed-wing aircraft. Comparable multiple plots could be developed for rotary wing aircraft.

Impact g profile plots. This program will sort out the impact 'g' data and plot the 3-axis accelerometer data against time on an expanded scale and determine max g values attained. See Figure 71.

Parameter synthesis. Certain parameters can be derived from other parameters and provided as inputs to basic plot/print and other programs. For example, altitude rate may be extracted from fine pressure altitude data (and or radar altitude if available). Pitch, roll and yaw angular rates could be derived from pitch, roll and directional data. Continuous normal acceleration could be obtained from the pitch rate, airspeed product.

Airframe-dependent cross correlation analysis. This analysis could be used to further refine data credibility analysis prior to the onset of an incidence and/or as an investigative technique in determining cause during the accident profile. For example, engine torques, speeds, rotor speeds and control input positions can be cross correlated for a particular airframe for data validity prior to an event and can be used to determine probable cause at the time of the event. As an additional example, control input can be correlated with airframe responses such as vertical flight g's, and derived angular and linear rates. This data could be compared with flight simulator responses. It may be practical to perform this program element on the particular flight simulator itself or utilize AIRS data as input conditions for comparative analysis in terms of aircraft response.

Once the data is permanently stored and a library is accumulated, further software can be generated to do Army aviation fleet wide studies. The scope of such studies would be affected by the complexities of manual input data inserted with initial AIRS data. For example, automatically taken AIRS data could be supplemented with other manual observations such as local conditions (day, night visibility, and ambient temperature). Other data such as Command, and squadron identifier could be added along with particular airframe related maintenance status and time usage factors. Once probable cause has been determined this data could also be tagged and added to the library for such future fleet wide studies.

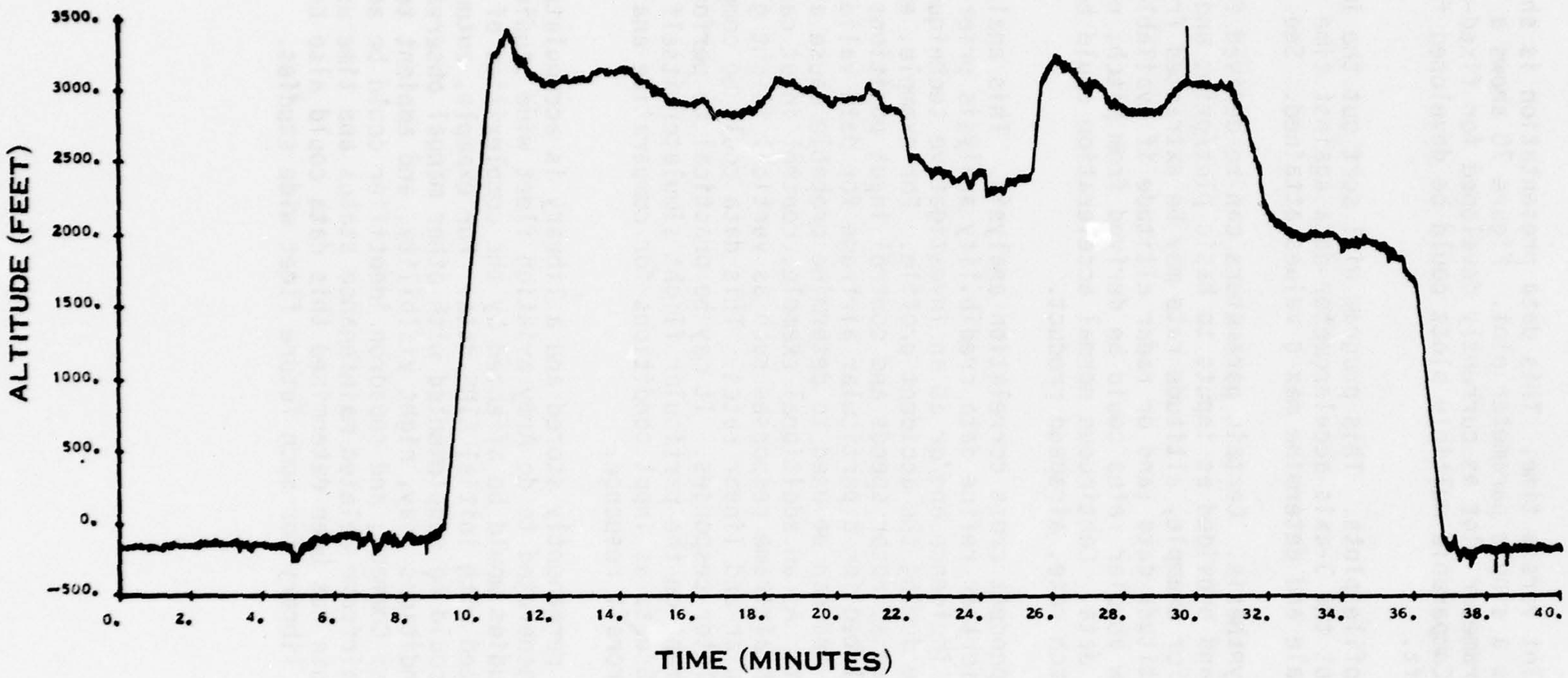


FIGURE 69. ALTITUDE PLOT

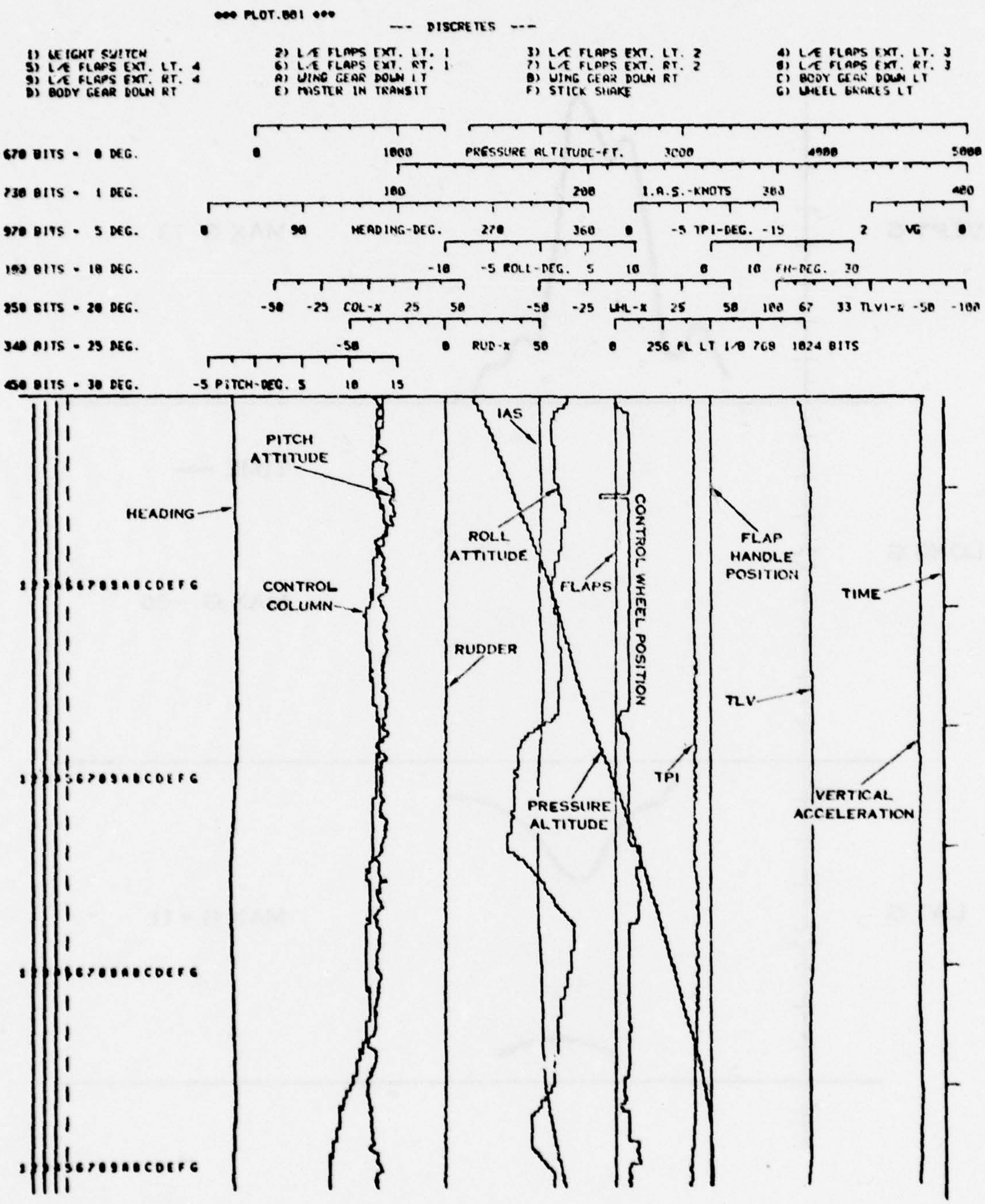


FIGURE 70. MULTIPLE PARAMETER PLOT

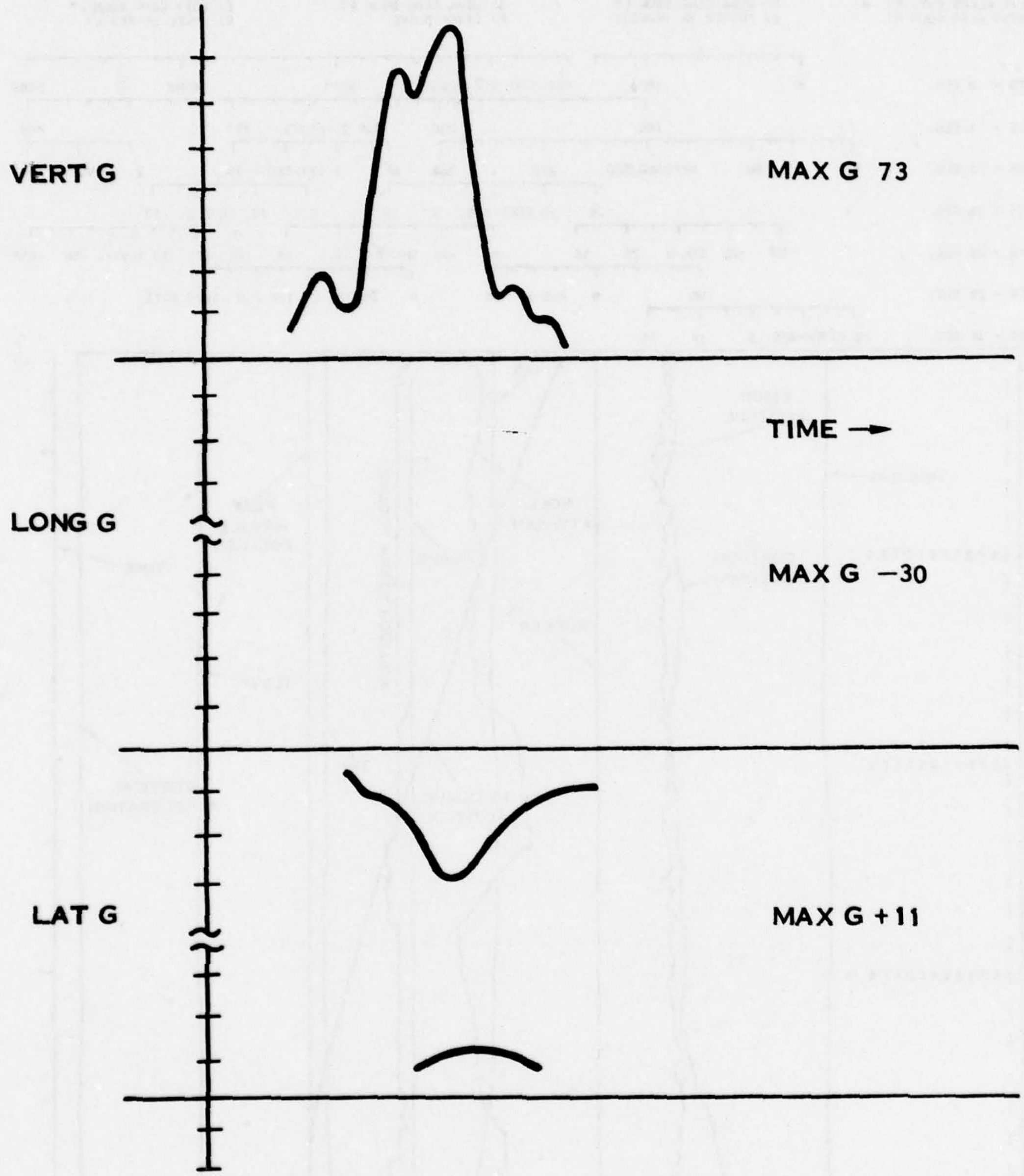


FIGURE 71. IMPACT G'S PROFILE PLOT

8.0 CONCLUSIONS

The conclusions derived from the AIRS preliminary design are as follows:

1. Using the current state of the art in electronic solid-state technology, an Accident Information Retrieval System with a significant input parameter complement (18 analogs and 18 discretes) and an average real time storage of greater than 30 minutes can be designed and produced at a size and weight significantly less than contemporary hardware.

2. The required features and design goals, as specified by the Army, are achievable using the recommended AIRS concept. The suggested design when implemented in hardware can be produced at a reasonable cost to the Army. The AIRS unit can be provided at this cost with survivability equal to or greater than that currently implemented in present crash recorders used in commercial aviation.

3. The unit weight is expected to approximate eight pounds with a volume of less than 200 cubic inches. The airborne system weight is expected to be approximately 10.0 pounds exclusive of brackets and wiring for the UTTAS or AAH application.

4. An AIRS unit of common design can be used for various types of helicopters. The UTTAS, AAH, UH-1H, and YCH47D were examined for potential AIRS installation. A high degree of commonality exists such that a single-unit design can be implemented for these aircraft with enough unit flexibility to handle parameter and software differences. In addition, a common design can be implemented and applied to other Army aircraft.

5. The AIRS electronics unit concepted is estimated to have a reliability of greater than 10,000 hours, and is virtually maintenance free. AIRS related sensors can be maintained by developing a small maintenance readout unit (MRU) for displaying sensor digital data on the flight line. To check for sensor wear a 1,000 hour interval data extraction and analysis at a a central computer facility can be employed.

6. Continued operation of the AIRS unit to measure impacts as high as 150 g's is feasible with power supplied to the unit and g sensors and interwiring intact. It is estimated that the recommended system unit cost increases 2% and the weight increases by .5 pound to provide this capabiltiy.

7. A portable ground unit (PGU) used to extract mass data for transfer to a central computer for investigative analysis is available off-the-shelf from a number of manufacturers.

8. Voice/Audio parameters were considered in detail as an integral part of this study. Inclusion of one channel of voice recording into the recommended AIRS unit with a recording time of approximately eight minutes, increases the unit cost by approximately 80%. Therefore, voice/audio was not included in the recommended system.

9.0 RECOMMENDATIONS

Based on the results of the Phase I & II program, it is recommended that:

1. A follow-on program be established for a prototype feasibility flight test based on the recommended system concept.

2. A protected solid-state memory module to meet the crash survivability criteria as given herein be constructed and tested.

3. Investigative analysis and feasibility testing on bubble domain memory devices be completed prior to establishing firm system requirements in order to conclude if these potentially lower cost devices can meet the established AIRS data storage survivability criteria.

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APPENDIX A

FLIGHT DATA FROM EVALUATION OF A FLIGHT DATA RECORDER

In the spring of 1975 an ARINC 573 flight data recording system was installed on a YCH-53E helicopter. This system consisted of a standard Flight Data Acquisition Unit (FDAU) and a Digital Flight Data Recorder (DFDR) used by many airlines. The parameters recorded are given in Table A-1. Unfortunately due to a wiring error, the attitude signals were not valid. The system was flight tested in April 1975. Plots of the results of that flight test are given in Figures A-1 through A-10. These plots also include the results that would be obtained from the floating limit data compression using the nominal limits.

This flight data is considered to be representative of a relatively busy flight. The flight consisted of hover at different rotor speeds, takeoff, climb, level flight at several different speeds, intentional shutdown of the number 1 and 3 engines, turns, approach, and landing. This flight also included an actual incident. At 31 minutes there was a failure of the number 2 engine due to foreign object damage (see Figure A-5). The total time was 40 minutes.

A data error can be seen at 29.7 minutes in altitude, airspeed, and rotor speed. This data can be recognized as an error because of the physical impossibility that these parameters could have made such a rapid change and because they happened simultaneously in more than one parameter. Errors like this are much less likely in a solid-state system than in the tape system used for the flight test.

TABLE A-1. FLIGHT TEST PARAMETER LIST

1. Airspeed
2. Altitude
3. Engine Torque No. 1
4. Engine Torque No. 2
5. Engine Torque No. 3
6. Lateral Stick
7. Longitudinal Stick
8. Collective
9. Rudder
10. Load Factor
11. Rotor Speed
12. Pitch Attitude
13. Yaw Attitude
14. Roll Attitude

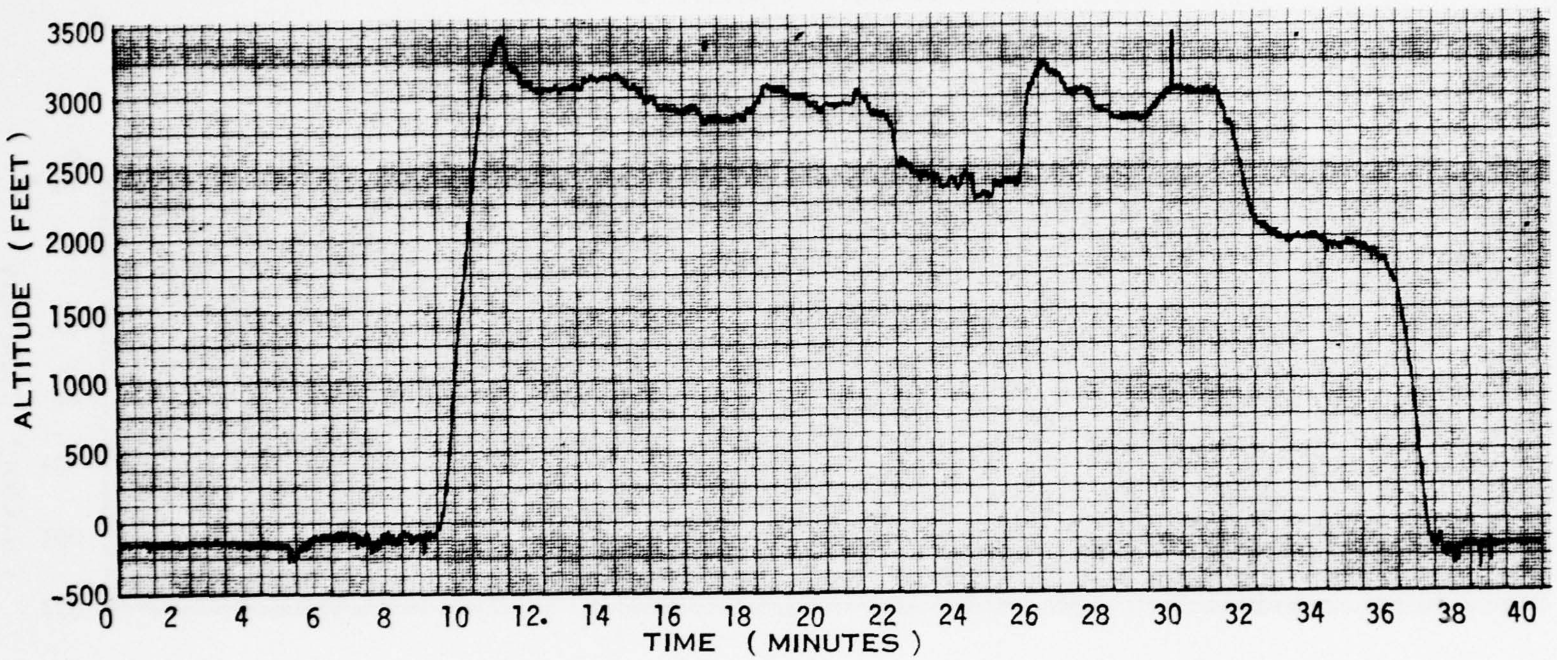

FIGURE A-1. ALTITUDE (LIMIT-50 FEET)

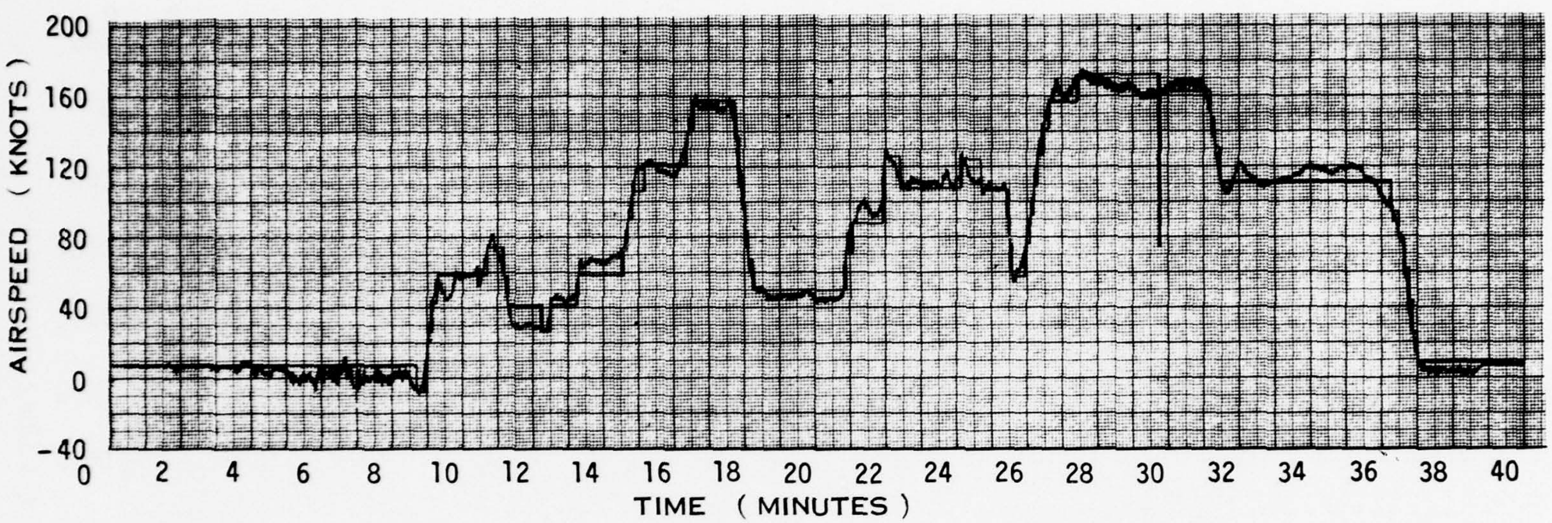

FIGURE A-2. AIRSPEED (LIMIT-15 KNOTS)

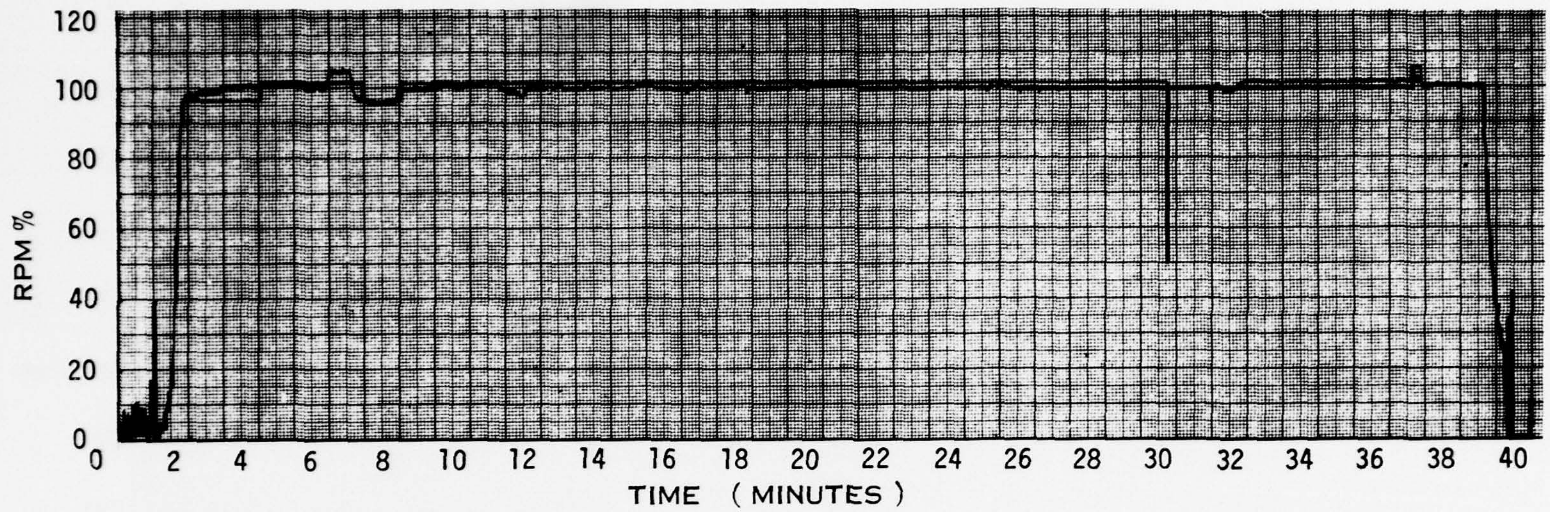

FIGURE A-3. ROTOR RPM (LIMIT-5%)

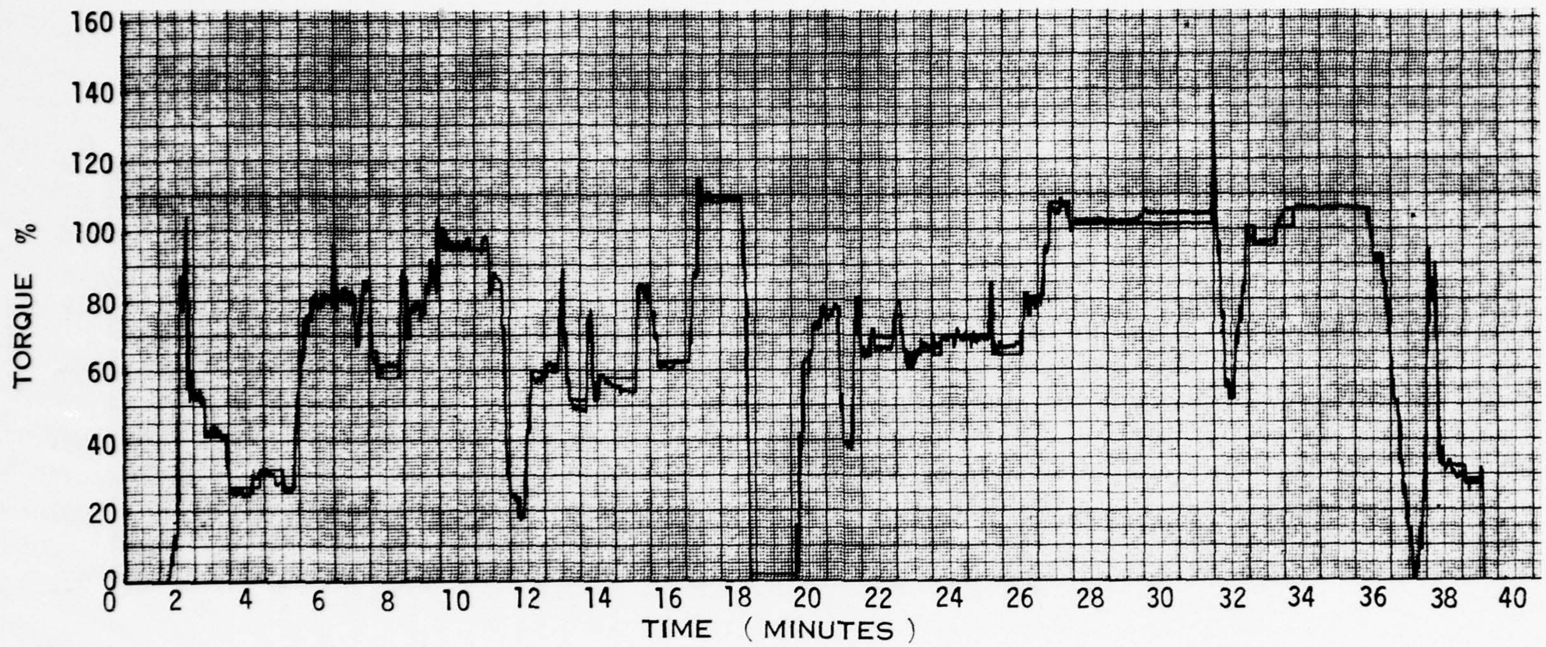

FIGURE A-4. ENGINE TORQUE NO. 1 (LIMIT-5%)

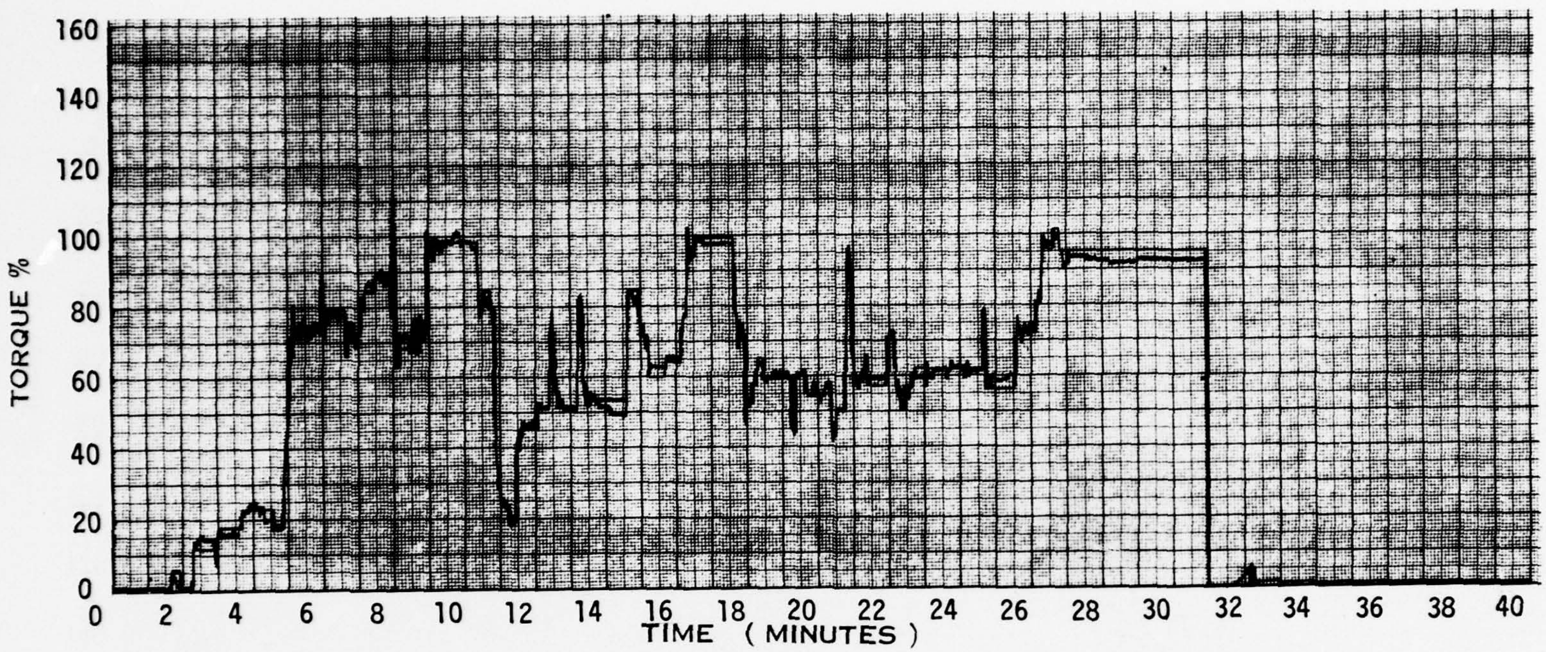

FIGURE A-5. ENGINE TORQUE NO. 2 (LIMIT-5%)

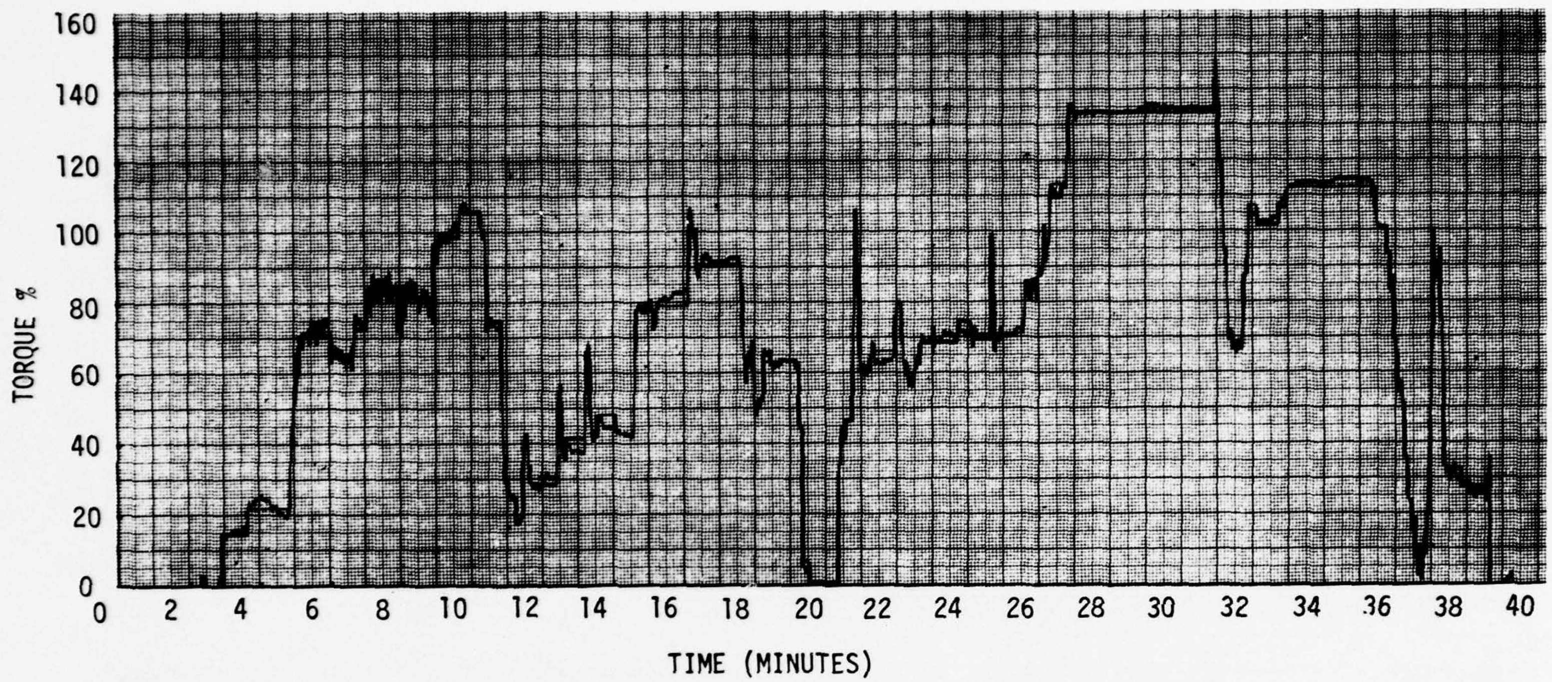

FIGURE A-6. ENGINE TORQUE NO. 3 (LIMIT-5%)

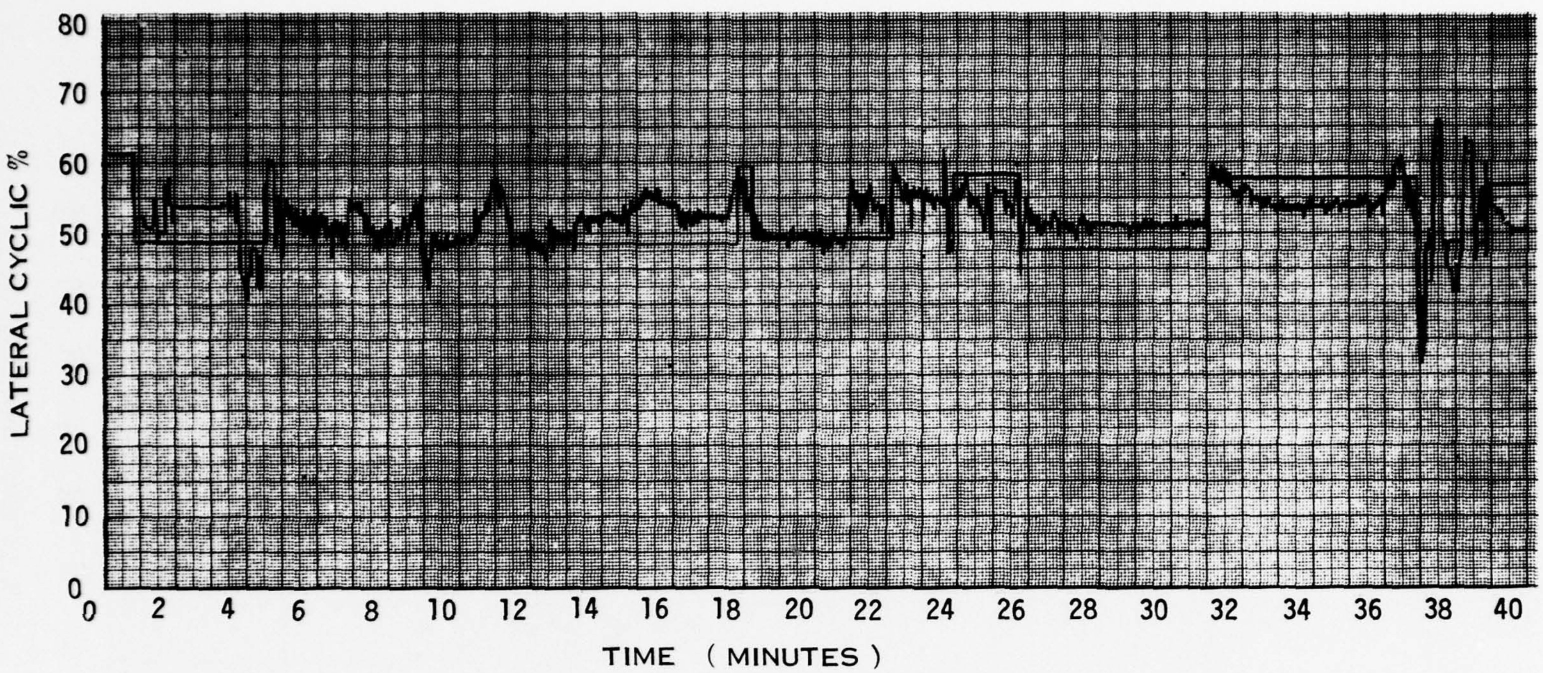

FIGURE A-7. LATERAL CYCLIC - TOLL (LIMIT-10%)

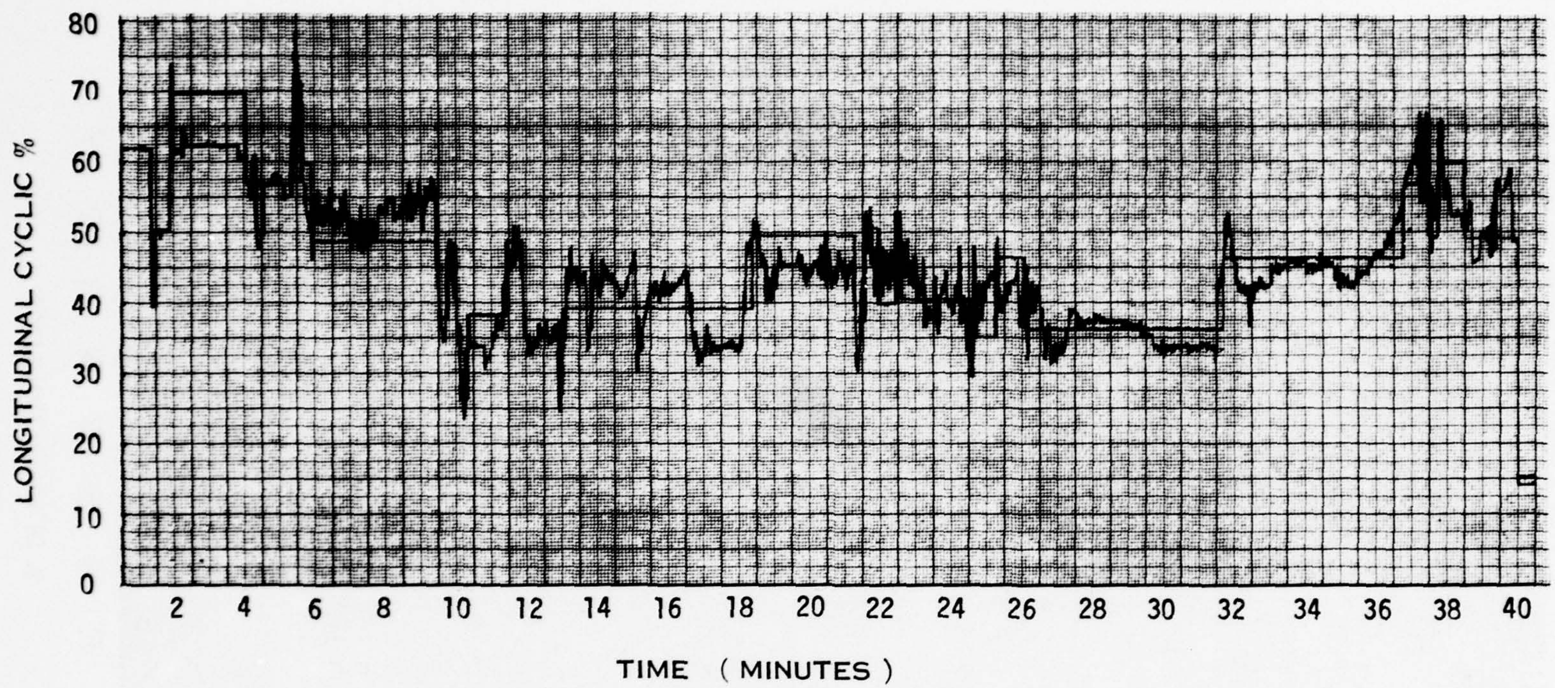

FIGURE A-8. LONGITUDINAL CYCLIC - PITCH (LIMIT-10%)

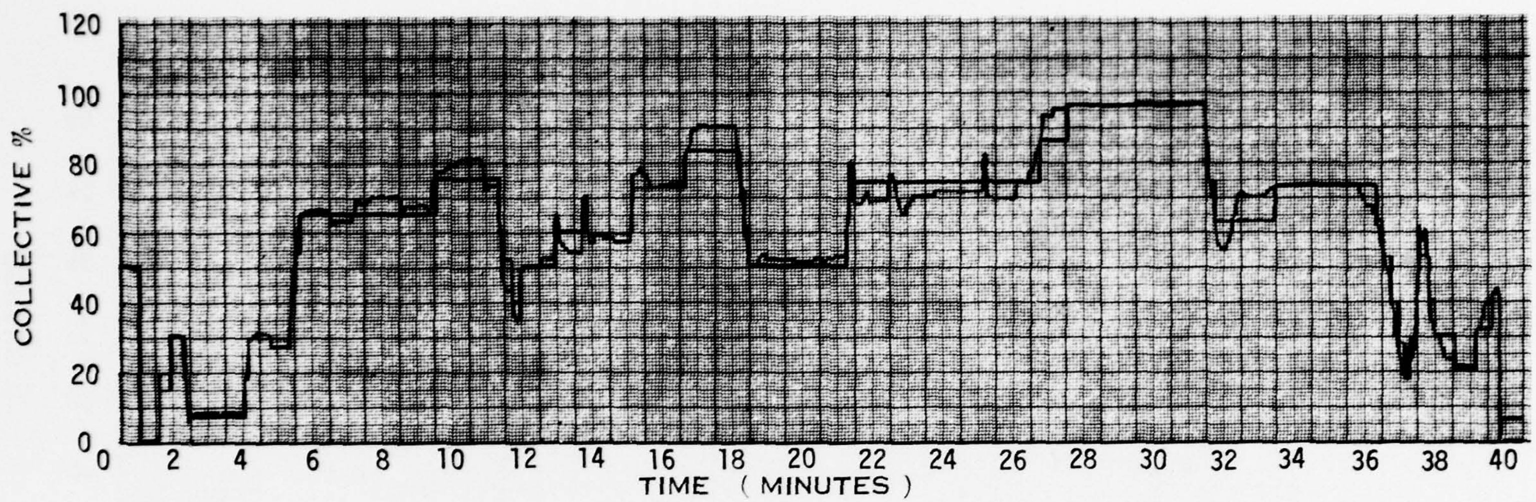

FIGURE A-9. COLLECTIVE (LIMIT-10%)

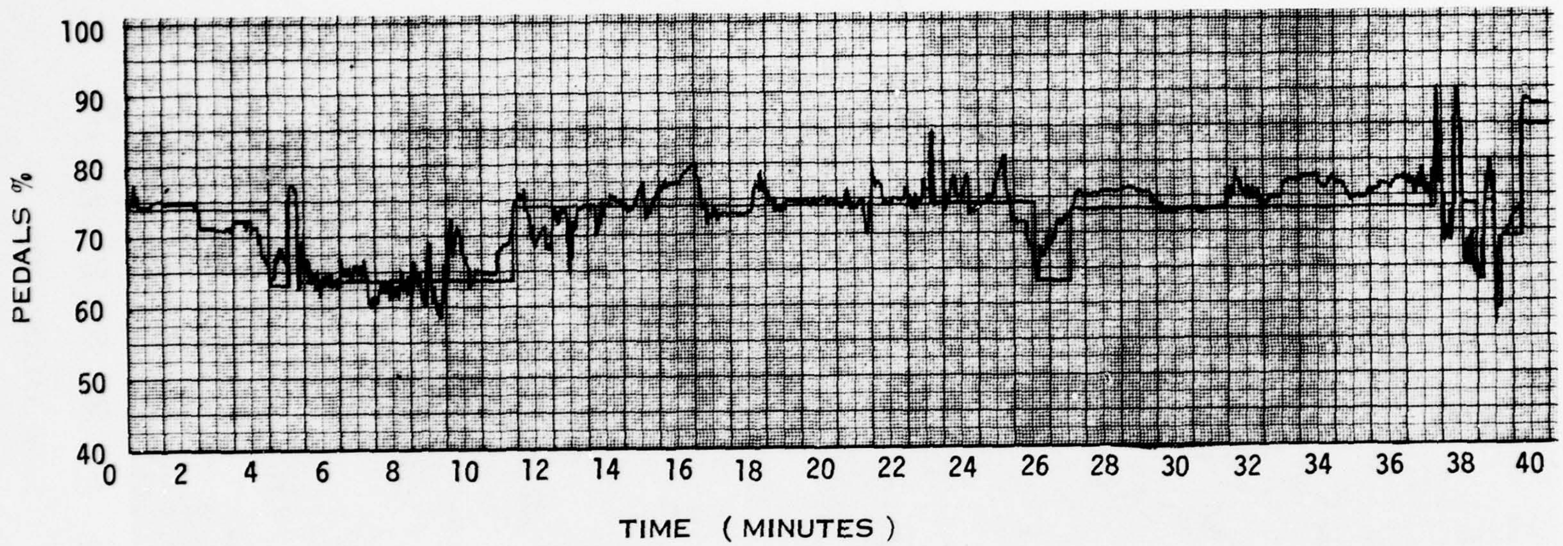

FIGURE A-10. PEDALS (LIMIT-10%)

ABBREVIATIONS

AIRS	Accident Information Retrieval System
ARINC	Aeronautical Radio Incorporated
A/D	Analog to Digital
BAUD	A digital word rate in coded samples per second
BIT	Built In Test
BOT	Beginning Of Track
BYTE	A subset of bits in a larger digital word structure
CCD	Charge Coupled Device
CMOS	Complementary Metal-Oxide Semiconductor
CRC	Cyclic Redundancy Check
CVR	Cockpit Voice Recorder
DEG	Degrees
DFDR	Digital Flight Data Recorder
DIP	Dual Inline Package
EAROM	Electrically Alterable Read Only Memory
EGT	Exhaust Gas Temperature
EMI	Electro-Magnetic Interference
EOT	End Of Track
FAR	Federal Air Regulations
F.S.	Full Scale
IC	Integrated Circuit
I.D.	Identification

ABBREVIATIONS cont'd

I^2L	Integrated Injection Logic
I/O	Input/Output
JAN	Joint Army/Navy
JTX	JAN Test Extra
KNTS	Nautical Miles Per Hour
LAMBDA (λ)	Failure Rate - Per 1,000,000 Operating
LED	Light Emitting Diode
LSB	Least Significant Bit
LSI	Large-Scale Integration
LSTTL	Low Power Schottky Transistor Transistor Logic
LVDT	Linear Variable Differential Transformer
MIB	Master Interconnect Board
MMH	Maintenance Man Hour
MNOS	Metal Nitride Oxide Semiconductor
MRU	Maintenance Readout Unit
MSB	Most Significant Bit
MTBF	Mean Time Between Failures
MTBUR	Mean Time Between Unscheduled Removals
MTTR	Mean Time To Repair
MUX	Multiplexer
NMOS	N-Channel Metal Oxide Semiconductor
NR	Rotar Rotational Speed
NVR	Non-Volatile Memory

ABBREVIATIONS cont'd

PCM	Pulse Code Modulation
PGU	Portable Ground Unit
PLA	Power Level Angle
PMOS	P-Channel Metal Oxide Semiconductor
PROM	Programmable Read Only Memory
PTT	Press To Talk
RAM	Random Access Memory
ROM	Read Only Memory
RS232	Electronic Industries Association Data Interface Standard
RSS	Root Sum Squared
TSO	Technical Standard Orders
T^2L or TTL	Transistor-Transistor Logic
VRMS	Volts - Root Mean Squared